Advanced Water Metering and Its Application in Low Income Communities

DEPARTMENT OF CIVIL ENGINEERING

Masters Dissertation

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ABSTRACT

In South Africa, it is a legislative requirement that all water supply points be metered (van Zyl, 2011). Conventional meters are mostly used as the main means of monitoring water consumption by South African municipalities. In the last two decades, the water metering industry has seen substantial developments with new capabilities added to the conventional water meter, known as advanced meters. These advanced water meters have capability of processing, storing and communicating data without the need of human intervention. As such they come with desirable capabilities for both consumers and municipalities. These include prepaid meters which are special type of advanced water metering technology that is mostly applicable in the low income areas of South Africa. However, advanced water meters have significant drawbacks, such as higher failure rates (due to electronics, batteries and more components), higher purchase and maintenance costs and susceptibility to tampering. It is therefore necessary to make a conscious and informed consideration when deciding on which metering technology to implement for different users. This could be achieved through having a technology evaluation framework.

The goal of this research was to develop an evaluation framework to help municipalities in the selection of appropriate advanced water metering technologies for application in low income communities. This goal was achieved through: determining the range of functionality of technologies both available and under development for advanced water metering; documenting case studies of both successful and failed implementation of advanced water meters, including social perception and impacts; developing an evaluation framework that can evaluate advanced water metering; and evaluating on technical, social, economic and environmental grounds.

The results from literature and case studies indicate that in low income communities, advanced water metering is mainly implemented for cost recovery purposes. However, some municipalities implement advanced metering schemes for water management and debt recovery. The most advanced water metering technology being installed in low income communities is prepaid meters. Prepaid meters have a potential to fulfill all the range of objectives that municipalities install advanced metering technology for. This technology is found to have high maintenance requirements due to high failure rate. For successful implementation, it is important that municipalities have adequate budget for repairs and maintenance or seek technical support from manufacturers.

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LIST OF ABBREVIATIONS

AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
FBW	Free Basic Water allocation
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
NGO	Non-Governmental Organisation
NRW	Non-Revenue Water
O&M	Operation and Maintenance
WDM	Water Demand Management
STS	Standard Transfer Systems

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1. INTRODUCTION

1.1. Background

Due to population growth, industrial development and rising standard of living, the world is rapidly reaching the limit of its readily available water resources. Water conservation has become of paramount concern for many countries (Britton et al., 2013) and South Africa is no exception. Municipalities (in South Africa and other countries) are constantly struggling to meet the requirements for the rapidly increasing water demand because of shortage of resources and the current revenue flows for most municipalities are unlikely to be adequate to fund water services operations.

Metering is an important part of revenue collection for municipalities as well as a tool for demand management. To further improve on benefits of metering, the metering industry has made advancements in metering technology; this technology is continuously becoming more sophisticated and is called advanced metering technology.

In this study conventional water metering is a system of metering in which water users' consumption (water passing through a water meter) is measured and the periodic readings (e.g. monthly or once every three months) used for billing purposes (Puleo et al.. 2014). Due to limitations on functionalities of conventional water metering some municipalities are increasingly using advanced water metering which according to this study is a system of metering which has additional functionalities such as automatic meter reading, consumption data storage, data processing and communicating data without human intervention. These include prepaid meters; which have been mainly installed in low income communities and have had negative publicity in the press. A study by Thompson et al., (2013) however made a surprising finding that these meters are seen to be overwhelmingly positively in terms of debt management in majority of poor communities.

1.2. Motivation for this study

Advanced water metering technologies are believed to have several significant advantages over conventional metering as outlined in the literature. These advantages of advanced water metering in low income communities comprise the following:

- Assisting users to manage their Free Basic Water;
- Enhancing water demand management; cost recovery and water loss control.
- Saving operational cost for the municipality by eliminating conventional meter reading, billing and debt management systems;
- Providing simultaneous readings for multiple users and thus, allowing more accurate water balance calculations;

Advanced metering systems also have disadvantages, such as higher failure rates (due to electronics, batteries and an increased number of components) than conventional metering systems; higher supply and maintenance costs; susceptibility to tampering and vandalism; and concerns regarding the right of access to water as some systems contain the functionality to automatically cut consumers of the water supply. Advanced metering technologies, because of their newness, have many teething problems that will still need to be addresses. Municipalities considering whether or not to invest in advanced water metering solutions must understand the current and projected potential benefits together with risks and the experience of other municipalities in deploying these technologies (Nicholson et al.. 2012). Due to high capital, operation and maintenance cost requirements for implementing advanced water metering technology, it is important that technologies are implemented properly to ensure that the desired benefits are achieved.

Advanced water metering technology has been implemented in South Africa resulting in both desirable and undesirable outcomes. At the onset of this study, outcomes of the implementation could not easily be predetermined due to lack of knowledge of the technologies and the appropriate methods for implementing different technologies. If knowledge on available technologies and their respective functionalities is enhanced, the chances of implementation resulting in undesirable outcomes, will be reduced. Furthermore, if a detailed framework and guidelines on the selection of appropriate advanced water metering technologies for different applications is available, the likelihood of implementations resulting in desirable outcomes will be increased.

1.3. Research goal and objectives

The goal of this research is to develop an evaluation framework to help municipalities in the selection of appropriate advanced water metering technologies for application in low income communities. This aim will be achieved through the following objectives:

- Determining the range of functionality of technologies both available and under development for advanced water metering;
- Documenting case studies of both successful and failed implementation of advanced water meters, including social perception and impacts;
- Developing an evaluation framework for advanced water metering;
- Evaluating a selected case study based on technical, social, economic and environmental criteria.

1.4. Scope of the research

The framework for selection of advanced water metering technology will be determined in the South African context. This research will be based on evaluation of selected past and present implementations. Even though this is a study on advanced water metering technology, the framework developed will first and foremost, be applicable to advanced water metering technologies in low income communities. Water metering technologies to be considered are water meters at consumer points and not the entire water distribution system.

1.5. Layout of the report

Chapter 2 presents the literature on different types of advanced water metering technologies as well as their respective components that distinguish each type of technology. An outline of the application of each type of technology is followed by a brief overview of different case studies.

Chapter 3 describes the development of an evaluation framework. It outlines different input parameters together with their respective typical, low and high values that can be expected in low income areas. Descriptions of indicators and parameters are also given. The chapter concludes with a sensitivity analysis of the framework model.

Chapter 4 outlines the results obtained from the evaluation of past and present implementations using the evaluation framework developed in Chapter 3. An interpretation of the results of the evaluation is also given in this chapter.

Chapter 5 discusses the conclusions drawn from the evaluations, followed by recommendations for improvements.

Lastly, the appendices present relevant information used in this study including framework matrix, sample questionnaire, sensitivity analysis results and Ethics Clearance form.

2. LITERATURE REVIEW

In this chapter, relevant literature on water metering is discussed in order to develop a full understanding of the impact of technological advancements in water metering. A review is given of water metering technologies that are used to measure domestic water consumption, and covers different types of conventional water meters and advanced water meters and their applications. The different components of the technologies and drivers; which are the factors making advanced metering attractive; of implementations of technologies are reviewed. Drivers leading to the implementation of the technologies are categorised in terms of their potential economic, technical, environmental and social impacts. Lastly, this chapter gives an overview of case studies of water metering technology in South Africa and abroad.

2.1. Conventional metering

As described in the introduction, conventional water meters are defined as meters that only display readings on the devices themselves; and read by physically visiting the meters. Conventional water metering includes all systems and processes in which conventional meters are used for municipal water management. This implies credit sale of water to a consumer with consumption accumulating as a consumer's debt. The municipality remains responsible for debt collection and in extreme cases where a consumer's debt accumulates without payment, the municipality may decide to manually disconnect the consumer from the supply.

Conventional water metering has been widely implemented as an equitable way of making consumers pay for the water they use as opposed to "no-metering" where flat rates are charged depending on aspects such as household size and plot size. Conventional metering has mostly been implemented due to its economic efficiency, technical robustness and the environmental and social advantages it has over 'no metering' (the situation in which consumption is not metered).

Conventional water meters come in three basic categories namely:

- Mechanical meters
- Electromagnetic meters
- Ultrasonic meters

The first important distinction between the different conventional meters is the measuring mechanism; it is based either on mechanical, electromagnetic or ultrasonic principles. To measure the flow, mechanical meters use moving parts; electromagnetic meters use Faraday's law of electromagnetic induction, while ultrasonic meters use sound waves.

Mechanical Meters

Mechanical meters have moving parts such as a piston of impeller that detect the flow, and these meters can either be measuring the volume of water flow passing through them (volumetric meters) or infer the volume of water from the velocity (inferential meters) of the water passing through them (van Zyl, 2011). The accuracy of mechanical water meters deteriorates with time since they use moving parts to detect and measure the flow. This deterioration in accuracy is due to the wearing of parts and building up of particles in the meter; this leads to an increase in friction and makes moving parts require more force to move, hence it needs a threshold flowrate to set the moving parts in motion. Figure 1 shows examples of mechanical water meters installed at consumer points.

Figure 1: Mechanical meters

This category of conventional meters dominates the number domestic meters in low income communities. This group of meters are mostly mistaken to represent the entire conventional meters. Meters can also be distinguished from the other categories of conventional meters such as electromagnetic and ultrasonic meters through its components.

Even though a range of conventional meters exist as outlined later in this chapter, van Zyl (2011), in his book 'Introduction to Integrated Water Management', indicates that all water meters consist of four basic components, namely:

- Sensor
- Transducer
- Counter
- Indicator

Figure 2 shows a section of a conventional meter.

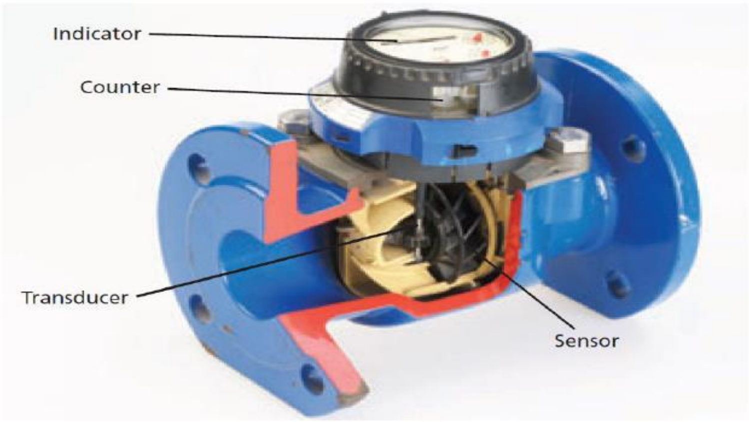

Figure 2: Section of a conventional meter showing different components (van Zyl, 2011)

<u>Sensor</u>

The sensor is a device that detects flow passing through the meter and it consists of a paddle wheel that is rotated by the movement of water passing through (van Zyl, 2011). The measuring mechanism dictates whether it is a volumetric or velocity meter. Meters that use sensors that detect the volume of water passing through by directly counting packets of water are called volumetric meters while meters that use sensors to measure the flow velocity and convert it to volume are called velocity meters.

<u>Transducer</u>

The transducer is the device that transmits the signal detected by the sensor to the counter. The transducer can be a spindle that is rotated by the paddle wheel of the sensor (van Zyl, 2011). The typical transducer consists of a thin mechanical spindle that is rotated by the sensor, but this type of transducer has the disadvantage that it can generate friction which reduces the meter's accuracy and causes wear in the meter over time. By contrast, the type of transducer that is frequently used in meters with dry compartments uses small magnets to transmit the signal into the dry chamber. But the challenge with this is that meters using magnetic transducers require special protection to ensure that external magnetic fields do not interfere with the meter reading (van Zyl, 2011).

<u>Counter</u>

A counter is a device that keeps track of the flow that has passed through the meter. The counter consists of a set of counter wheels or numbered discs similar to that of a car odometer (van Zyl, 2011). However, some meters have counters consisting of electronic devices that keep the volume of water reading in their internal memory.

<u>Indicator</u>

The indicator is a device that communicates the reading to the meter reader. The indicator consists of the numbers on the counter wheels that are visible on the face of the meter (van Zyl, 2011). However, there are other types of indicators such as rotating pointers and electronic displays. According to the SANS standards it is essential that the indicator has a transparent window and shows the meter reading in an easily readable way (SANS, 2006).

Electromagnetic meters

Electromagnetic water meters use a principle of electromagnetism called Faraday's Induction Law, to measure the velocity of the water passing through them (van Zyl, 2011). Faraday's law describes the phenomenon of a conductor moving through a magnetic field and inducing an electric voltage across the ends of the conductor (van Zyl, 2011). With electromagnetic water meters, an electric signal is measured when ionised water flows through a magnetic field. The faster the water flows, the more voltage is created and measured (Sensus, 2012); and since voltage is proportional to velocity, as water velocity increases, voltage increases and the volume measured increases. Figure 3 shows the electromagnetic water meter measuring mechanism.

At region B, the two plates are charged to create a magnetic field. External energy (from a battery) is required to charge the plates and create opposite polarities. It is the difference in polarity that creates the magnetic field in the pipe. As water passes through the pipe, the electric signal is measured and translated into velocity (of water passing through the two plates).

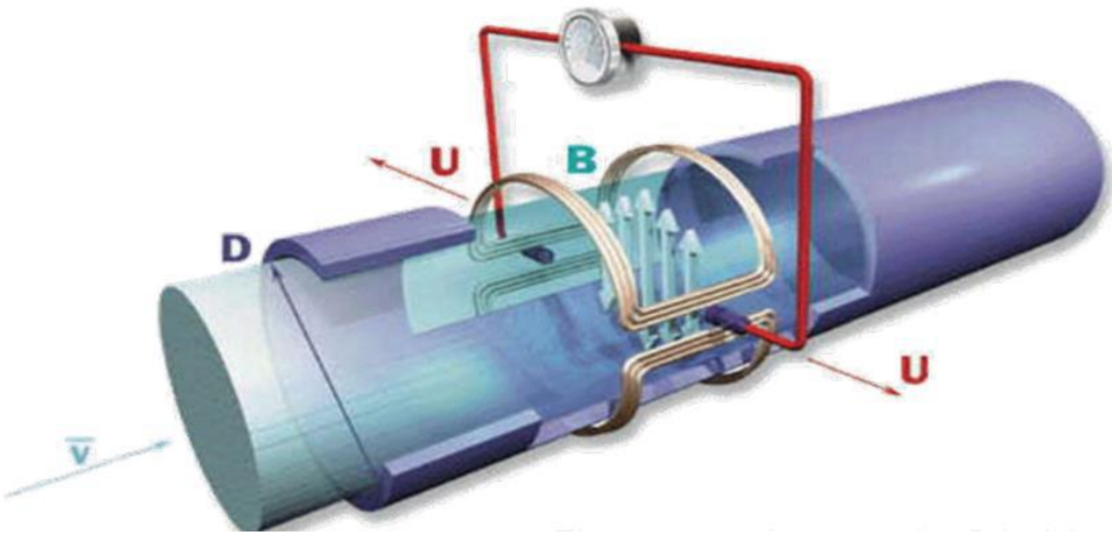

Figure 3: Electromagnetic water meter mechanism (Sensus, 2012)

Electromagnetic water meters do not have moving parts and therefore have the advantage that their measuring accuracy is unlikely to reduce with aging; the measuring performance remains linear through-out the flow range and these meters maintain accuracy for both forward and reverse flow directions (Sensus, 2012). They have the disadvantage though that; creating the magnetic field to sustain the right electrical environment for accurate readings requires a controlled magnetic field and a considerable amount of energy (Sensus, 2012).

Ultrasonic meters

Ultrasonic water meters use ultrasonic transducers to send sound waves upstream and downstream through the water, the difference of which is then translated into the volume of water (Sensus, 2012). Since there is no measuring element in the path of the water flow, there is no reduction of accuracy over time. Ultrasonic water meters however have the disadvantage that their accuracy can be affected by suspended particles or air bubbles in the water (van Zyl, 2011). They also require sound power and the high sampling rate requires high accuracy which results in heavy power consumption (Sensus, 2012). However, battery life could be conserved by increasing measuring intervals though that compromises the accuracy of a meter at low flow rates.

2.1.1. Technical specifications of conventional water meters

The South African Bureau of Standards (SABS), the national institution responsible for regulating the quality of South African goods and services, sets technical specifications for water meters and metering systems, i.e. the South African National Standards (SANS1529) to maintain the quality and requirements for water meters used in South Africa. Other countries have different standards, but the focus for this study is mainly on SANS. All the specifications are as per SANS (2006) and apply to mechanical meters with diameters not exceeding 100m. These are the meters widely used for domestic consumption in South Africa.

It is easy to determine whether locally manufactured meters are SANS compliant as they have an SABS mark on them. However, determining SANS compliance for products that are manufactured abroad and newly evolving is quite a challenge as they comply with the standards of the country of origin in the first instance. Compliance with other standards does not necessarily imply compliance with SANS. Some of the important basic parameters to check compliance with SANS are outlined in the following paragraphs as per SANS 1529, (2006):

- It is a requirement that housings for electronic and other components of the measuring system intended for outdoor installation are durable. Metal housings must be protected against corrosion;
- A meter designed to operate when installed horizontally only or vertically only must be marked to indicate that orientation. Also, domestic water meters must be designed to operate under a nominal working pressure of 1 600 KPa. However, with possibility of meters designed for different working pressures, the designed working pressure must be marked clearly;

- Meters should be designed such that they can withstand reversal flow without any change in their metrological properties. It is also required that meters designed for reversal flow be clearly indicated.

- The meter is expected to have a minimum permissible relative error of 5% in the lower zone, and 2% in the upper zone. This must be ensured after installation.
- It is also required that two clearly contrasting colours (for example, black and red) are used for the numbering and scale marks of the indicator elements, to differentiate between multiples and submultiples of the cubic metre.

2.1.2. Drivers of conventional water metering

The implementation of conventional water metering has mostly been driven by its economic efficiency, technical robustness, and environmental and social advantages over flat rate tariffs. Drivers of conventional metering are therefore divided into the above-mentioned categories

Economic benefits

According to van Zyl (2011), measured consumption forms the basis of most water accounts, and thus affects municipal revenue directly as water meters are the cash registers of water suppliers. From a financial perspective, accurate water meter systems improve water sales and thus municipal income. Metering makes it easy for municipalities to implement water tariffs that can control water consumption and municipality income, and cross-subsidise needy consumers.

The main financial benefit of a meter consists of the revenue generated from water that is measured and paid for by the consumer. However, there are also indirect financial benefits that could be achieved from a meter, such as lower levels of leakage in the system due to better estimations of the levels and location of system leaks and the benefits derived from better system operation and planning (van Zyl, 2011). The reduction of water losses such as Non-Revenue Water (NRW) and real losses are of financial benefit to the municipality as it results in reduction of water treatment costs and many other costs associated with the distribution of water.

Technical advantages

Many of the technical benefits of water meters, such as accurately measuring municipal water purchases, reducing water losses, and identifying and removing illegal connections, also have a positive impact on the finances of municipalities (van Zyl, 2011). Accurate metering leads to increased revenue from water sales, i.e. greater robustness of the technology is associated with more accurate metering which results in increased financial benefit for the municipality.

Due to the fewer components, conventional water meters require simpler maintenance as compared to advanced water meters. It only requires simple but important actions, such as cleaning of strainers, cleaning and repairs of meter boxes, fixing leaks and replacing damaged registers and register covers (van Zyl, 2011).

Environmental benefits

Most conventional water meters do not require power for their operation and therefore no batteries are involved; this makes them environmentally friendly as there is no requirement for battery disposal and energy consumption.

Metering leads to reduction in water consumption for individual consumers. This reduction in consumption serves as an environmental benefit as water resources are conserved. Furthermore, the reduced consumption reduces energy and chemical usage in the water treatment process as the amount of water that has to be treated is reduced.

Social benefits

Water metering provides an equitable basis for charging consumers based on the amount of water that they consume (van Zyl, 2011). This has social benefit as it allows fair cross-subsidisation with needy consumers receiving a free basic amount of water. The cross-subsidisation along with a relevant tariff regime is made possible through conventional metering; however, this is also possible with all the other metering systems.

The usual social benefit of conventional metering is that though implementation of a rising block tariff, high-income households and commercial properties with high consumption are charged at a profit which is then used to finance the Free Basic Water (FBW) for poor communities.

2.1.3. Drawbacks of conventional metering

Due to manual meter reading and billing calculations, conventional metering may be susceptible to human error and can open opportunities for corruption of human meter readers as well as illegal users. Sometimes users disconnect the water supply line from the water meter and collect water directly from the supply line with the help of water meter readers. The manual meter reading process of having to visit the meter can also be time consuming and tiresome as some meters are great distances apart, especially in rural areas.

The fact that conventional metering relies on manual reading for billing purposes, access to the meters can be a problem in some areas; this leads to municipalities having to estimate consumption which makes the system unreliable. Difficulties with this system are the frequency and reliability of meter reading, problems with sending bills and the reluctance or inability of consumers to pay (Malete, 2010). Preparing a bill is a task that needs additional personnel from the municipality, and sending a bill to the customer comes with postage and printing costs. Furthermore, in some areas or instances there are no formal cadastral address as for customers and this makes sending bills difficult or almost impossible.

2.2. Advanced metering

As defined earlier, advanced water metering is a system which goes beyond manual periodic reading of a water meter for billing purposes. This type of metering often requires additional components to allow for additional functions such as:

- ability to process data
- ability to store data
- ability to send and receive information and signals
- meter functions can be automatically controlled (e.g. through an automated valve).

There are different types of advanced water metering systems with different names. In this study the following types of advance water metering systems are reviewed:

- Automatic Meter Reading (AMR)
- Advanced Metering Infrastructure (AMI)
- Water Management Devices (WMDs)
- Prepaid Water Metering

With these types of metering technologies, there is a lot of overlap when it comes to capabilities and functionalities. The distinguishing aspects dictate application of the technologies. These are not completely exclusive categories and can be mixed up. For instance, it is possible to have an AMR system with a prepaid meter. The above mentioned categories are just typical categories used in literature.

2.2.1. Automatic Meter Reading (AMR)

AMR refers to any system that allows automated collection of meter readings (usually by radio transmission), without the need for physical inspection (Hope et al., 2011). McNabb (2011) refers to AMR as a one-way communication from the meter to the billing system and includes the following:

- walk-by
- drive-by; and
- fixed network

- ***Walk-by-*:** The meter is connected with wires to a device located on the outside of a building (McNabb, 2011). Even though a physical visit by a meter reader is still required, the meter reader does not have to go onto the consumer property, eliminating the safety hazard for both the meter reader and the consumer. With this technology, the meter reader uses a handheld device which receives consumption information via infrared or radio frequency (McNabb, 2011). The information can later be downloaded into the meter billing system and bills are prepared and sent to the consumers. Even though the meter reader walks by the property boundaries without going onto consumer properties, by intuition, this should result in more consumer meter readings be read. McNabb (2011) however argues that this method does not increase the quantity of information collected. House (2010) on the other hand, claims that even a simple electronic or offsite meter reading system, in which a handheld device equipped with a radio reads meters from a distance, will save substantial labour. The major advantage of this method is elimination of consumption estimation that could be caused by lack of access to water meters.
- ***Drive-by-*:** In this method of meter reading, the water meter requires a radio frequency transmitter that is read by the meter reader within a vehicle driving past the meters. The information is collected on a laptop in the vehicle which has vendor-supplied software that matches the account information, location and meter register information and prepares it for download to the billing system (McNabb, 2011). Similar to the walk-by method of meter reading described above, McNabb claims that the drive-by method also does not increase the number of meter readings, because of the time and expense of driving the routes (McNabb, 2011).

  The number of meter readings collected depends on the speed at which the vehicle is travelling. The specified speed at which vehicles should be travelling when using the drive-by method could not be determined from the literature. However, some manufacturers claim their AMR technology can function at 50km/h. Some roads and routes may however not allow vehicles to drive at this speed.
- ***Fixed network-*:** This is the technology that is often mostly referred to as AMR while in fact AMR also includes walk-by and drive-by. In the fixed network, the signals from a single meter are transmitted and then collected at a central receiving station if close enough, or to repeaters and then to the central receiving station (McNabb, 2011). This

allows continuous water consumption readings from multiple meters at the same time. Unlike walk-by and drive-by methods, a fixed network results in increased number of meter readings. However, fixed networks might be less efficient in rural areas due to high capital cost. Readings could still be effectively done using drive-by and walk-by methods which cost far less.

Drivers of AMR

AMR is driven by benefits that the technology has over conventional water metering. As water utilities and municipalities shift from conventional meters to AMR, they enjoy the following benefits (House, 2010):

- increased revenue from previous non-revenue water
- reduced meter reading costs
- safety and security benefits
- reduced greenhouse gas emissions
- help in identifying and pinpointing customer and system losses.

These AMR benefit water consumers and water utilities economically, technically, environmentally and socially.

***Economic drivers*-:** By deploying AMR, water utilities may require fewer meter readers and thus reduce meter reading costs. However, it is not advisable to completely eliminate meter reading as it has the benefits of verification of data and inspection of aspects like illegal connections. AMR can reduce associated meter reading costs such as salaries, benefits, vehicle costs and other general expenses (House, 2010). However, it is worth noting that in rural areas where meters are far apart and very few meters are covered by the system, it might not be cost efficient to install AMR due to the high capital cost requirements for setting up the infrastructure.

***Technical drivers*-:** The presence of additional components enabling one-way communication from the water meter to the municipality, enables municipalities to monitor consumption through efficient and quick acquisition of consumption information. This functionality could help municipalities reduce their billing cycles due to quick acquisition of consumption data.

***Environmental benefits*-:** AMR systems require fewer vehicles in the meter-reading process. This reduces pollutants, dust and greenhouse gas emissions. Also, reduction in water consumption and leakage leads to less water being treated and supplied to customers, and therefore there is an environmental benefit of less energy and chemicals used for water treatment.

***Social benefits*-:** AMR has a high ability to monitor water consumption. By monitoring water consumption when all water systems are turned off, enables quick leak detection and therefore, reduces quarrels between consumers and municipalities over high bills.

Drawbacks of AMR

The technical sophistication of AMR makes it difficult to maintain as containing many, such systems are more likely to fail. It also relies on communication networks that are controlled by different entities.

AMR communication relies on power and is mostly powered by batteries. This adds to the maintenance requirements of AMR systems as batteries have short life span. Batteries are also less environmentally friendly.

Application of AMR

AMR technology is often used in areas where access to water meters is a problem like in areas where water meters are inside consumer properties instead of moving meters outside (McNabb, 2011). AMR also make meter reading more efficient and can significantly cut on meter reading costs.

2.2.2. Advanced Metering Infrastructure (AMI)

AMI is a technology that automatically collects consumption data from water meters and sends it to a central station for analysis and billing purposes. Unlike AMR, AMI is a two-way communication between the central station and the water meter in a sense that information can also be sent from the central station to the meter or consumer. This technology gathers data over a wide area from water meters and other devices at customers' premises, and sends it via telecommunications to a remote central location (Blom et al., 2010). The electronic data stream from the register can contain the meter's current reading as well as additional information such as cumulative water consumption, peak demand, and alarm flags. Conventional meters can be upgraded to AMI by adding meter reading applications, receivers and meter interface unit.

Components of AMI

Advanced metering infrastructure (AMI) basically comprises the following devices through which information is transmitted from the meter to the consumer or vice-versa:

- transmitter
- data logger
- gateway
- consumer interface

***Transmitter*-:** A transmitter is the most basic component of AMI which transmits water meter readings to a remote location in the form of radio waves (Blom et al., 2010).

***Data logger*-:** A data logger is a device which can both store and send interval data (Blom, et al., 2010) and in the same way as the transmitter, can be attached to a meter. Data loggers are able to log data on adjustable time scales which can range from one recording per second to one recording per month (Blom et al., 2010). One immediate advantage of interval data logging is that it simplifies leak detection. Leaks are identified by noticing sustained constant water flow over certain time intervals. Software analysis can calculate the precise amount of water lost in a time interval as shown in Figure 4:

Figure 4 shows water consumption data indicating two stages of a leak. The fluctuating consumption flow rate that does not get to a minimum flow rate of 0 in a period of more than a day indicates a leak as shown on the graph. However, it is worth noting that this is a feature provided by any logger but with AMI this graph and consumption profile can be sent to the central station or the consumer who can access it remotely and hence initiate repairs early.

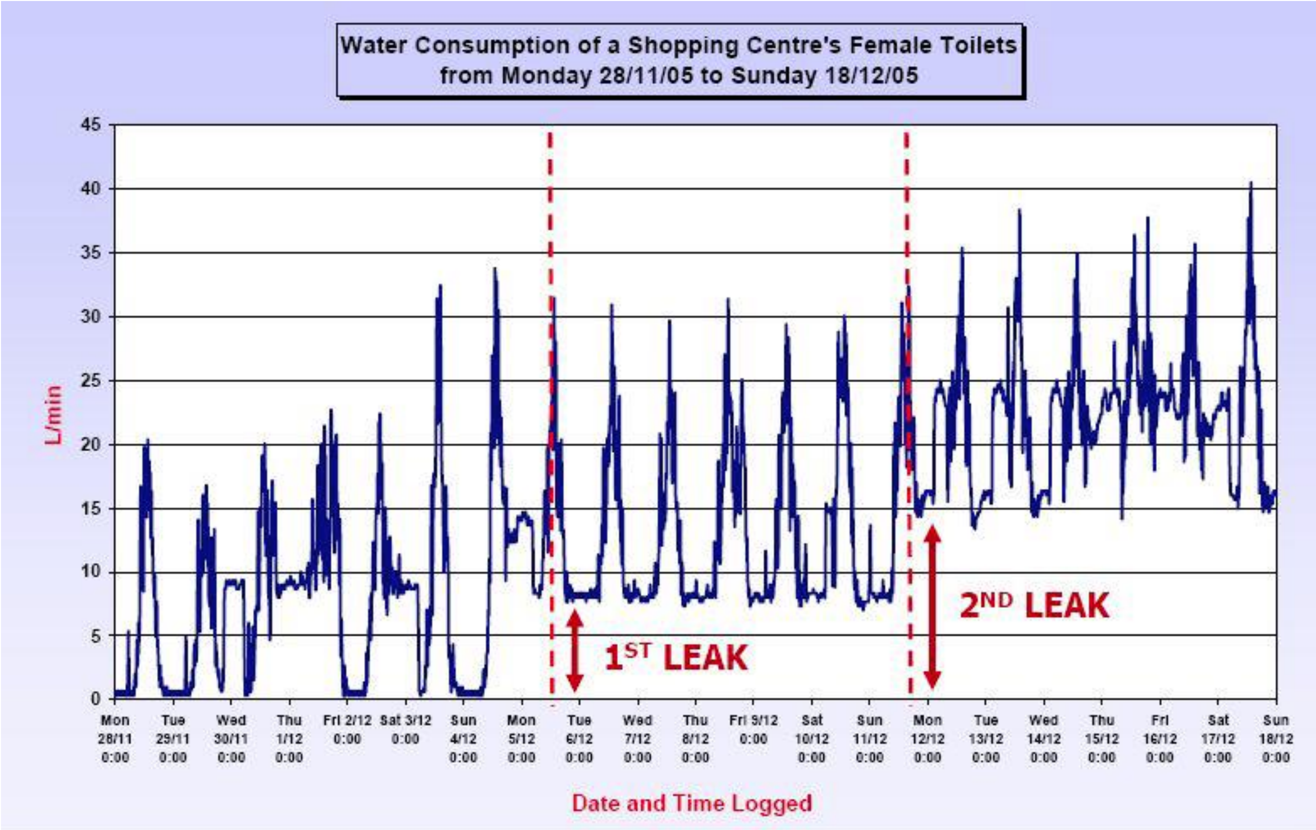

Figure 4: Water usage analysis (Blom et al., 2010)

***Gateway*-:** A gateway is a device that receives signals from data transmitting devices and relays the information to a distant location (Blom et al., 2010). AMI and data loggers typically use radio transmitters to send information to a gateway which then relays all end-use data via GSM networking. A gateway acts as a larger data logger and stores multiple data points and transmits them in packets to the utility or municipality.

***Consumer interface*-:** The consumer interface allows a person to interact with a piece of technology (Blom et al., 2010). An in-home display, an electronic water bill, and an online web portal are all examples of consumer interfaces that could be made available to a homeowner to view their water consumption data .

Drivers of AMI

AMI is driven by all the benefits of AMR stated earlier. However, AMI has additional benefits to that of AMR such as, AMI has more advanced functionality as it enables the acquisition of real-time consumption information for the municipality and/or consumer. Furthermore, AMI enables water utilities to send pricing information to the consumer and hence initiate water saving programs. These additional benefits of AMI bring economic, technical, environmental and social advantages to the consumer and the municipality.

***Economic drivers*-:** Conceptually, with the use of AMI, municipalities are able to implement time of use rates and tariffs that encourage water saving and hence reduce the cost of providing water to consumers (Nicholson et al., 2012). Introduction of higher peak hour tariffs makes consumers refrain from using water during peak hours whenever possible. This could become an economic benefit to the municipality as smaller diameter pipes will be adequate as mains in water distribution systems. However, case studies on which AMI was implemented for that could not be found.

***Technical drivers*-:** The robustness of AMI brings in more important functionalities such as water consumption monitoring and leak detection. The ability to send feedback and interact with the consumer through the user interface promotes proactive measures to control consumption.

***Environmental benefits*-:** AMI often has leak detection functionality and the capability to notify consumers through alarms about the presence of a leak in their property or unusual excessive consumption. This reduction in water consumption and leakage leads to less water being treated and supplied to customers, and therefore there is an environmental benefit of less energy and chemicals for water treatment being used.

***Social benefits*-:** Notification of unusual excessive consumption and the presence of leaks reduces the chances of unexpected high bills and therefore, reduces quarrels between consumers and municipalities over high bills. Furthermore, it reduces conflict amongst household members. For instance, parents blaming children or other family members for wasteful use that lead to a high bill. Accessing real-time consumption profiles can help resolve such conflicts in families.

Drawbacks of AMI

In addition to the previously mentioned drawbacks of AMR, AMI have a high financial requirements and in some areas the infrastructure may not support this type of technology (Malete, 2010). These challenges make feasibility of AMI in low-income communities questionable because the payment level for water services is relatively low; therefore, financing the technology may be a burden to the municipality.

Application of AMI

Due to the high capital, operation and maintenance requirement of AMI, it is mostly implemented in high-income communities where payment for municipal services is not a problem and the education level of consumers is adequate to enable them to interpret information sent to them. Furthermore, the major driver of AMI is water demand management and water conservation because of its inherent leak detection capabilities. Therefore, AMI is more effective in high-income areas where consumers can afford to do their own leak repairs should any leaks be detected. Commercial centres, business parks and industrial properties can significantly benefit from AMI.

2.2.3. Water Management Devices (WMDs)

WMD is an electronic control valve capable of controlling the flow of water to a consumer. This device, when linked to a pulse output water meter, is mostly used to limit the volume of water used in low-income communities to basic free water levels (Thompson et al., 2013). This device consists of a mechanical water meter and an electronic device that regulates the supply. This device is sometimes used by other manufacturers as a component of prepaid metering systems.

This device is installed on the downstream side of the water meter and shows the cumulative consumption in a day or month depending on how the allocation is distributed. Most municipalities set the device to limit the allocation on a monthly basis; the meter screen reads zero at the beginning of the month and shows the cumulative consumption. The consumer can calculate the amount of allocation remaining by subtracting the volume shown on the screen from the monthly allocation (which is 6000 litres for most municipalities).

As cited by Thompson et al. (2013), USC (2011) claims that a WMD is capable of controlling the flow of water to a domestic consumer at full pressure and can be configured to do the following (Thompson et al., 2013):

- dispense a fixed daily or monthly quantity of water, thereby providing the ability to limit a consumer to a finite (or pre-negotiated) level of supply;
- be linked to a fixed (flat rate) tariff, and limit consumers to voluntarily limit consumption according to their budget;
- be shut off remotely, or operate at reduced daily or monthly quantity;
- default to a trickle flow if required, once the full pressure allowance has been consumed;
- allow for efficient disconnection or reconnection of the supply.

Figure 5 shows a typical WMD configuration:

Figure 5: Water Management Device (Thompson et al., 2013)

Application of WMDs

These devices are used to limit water consumption mainly in low-income communities where consumers cannot afford to pay for water services. Municipalities tend to use the devices to limit poor consumers to the Free Basic Water allocation (FBW). Municipalities install these devices free of charge on poor consumers' properties with the promise of writing off the debts if consumers manage their water use and keep it within their free basic allocation.

2.3. Prepaid water metering

As defined by van Zyl (2011), prepaid meters are water meters with built-in processing units and a mechanism that can automatically close a valve and therefore shut off a consumer's supply. The shutting down of the valve is programmed to occur after a meter has dispensed certain amount of water depending on the water purchased or water allocated to the consumer. Consumers purchase water in advance, and the amount purchased is transferred through a token or electronic signal to the meter (van Zyl, 2011). Once the available credit on the meter has been used up, the prepaid meter automatically shuts down the water supply. In some cases, the supply is shut down completely, while in others a small flow through the meter is maintained.

2.3.1. Historic development of prepaid water meters

Schnitzler (2012) describes a prepaid meter as a small technical device that measures municipal services such as electricity or water, with the device having an additional capability of automatically disconnecting users in cases of non-payment. As outlined by Schnitzler (2012), the first prepaid meter was developed in the 1980s by South African electrical engineer Peter Clark due to the widespread anti-apartheid rent boycotts that were prevailing in the South African townships. The financial problems that were caused by the non-payment of municipal services necessitated a technical solution to the problem; this lead to invention of prepaid metering.

Marah et al. (2004) claims that, following the invention of prepaid metering for municipal services, the first prepayment water meter was marketed in South Africa in 1992. Schnitzler ascertains that a new prepaid metering technology that leads to automatic disconnection when credit runs out was pioneered by Conlog, a South African firm directed by the late ANC leader Joe Modise once he retired as Minister of Defence in 1999 (Schnitzler, 2012). However, according to Ruiters, in the water sector, the use of prepaid meters for urban households started extensively only in 2003, while in rural areas with standpipes they had been in use since 1996 (Ruiters, 2007).

Components of prepaid meters

As described by Heymans et al., (2014) in their research of prepaid metering, prepaid water meters consist of the dispensing unit, a vending system, and a database to record customer purchases and consumption. The dispensing unit (referred to as a prepaid meter in this study), comprises of the following basic components:

- mechanical water meter
- built-in processor and shut-off valve
- token and token socket

- built-in memory
- battery.

- ***Mechanical meter-*:** This is the conventional meter that measures the quantity of water supplied to the consumer when a shut-off valve is open to dispense the water. The meter reading is sent to the built-in memory for storage.
- ***Built-in processor and shut off valve-*:** The built-in processor controls the opening and shutting down of the shut-off valve as water supply to the consumer depends on availability of credit. With the built-in processor, the valve can either be completely shut or partially shut to allow a small flow of water to the consumer when the credit is exhausted.
- ***Token and token socket-*:** This is the device which is used to buy credit and transfer it to the meter to dispense water. It acts as a key to receive water. Water metering information is transferred through the token to the management system at municipalities (Malete, 2010).
- ***Battery-:*** The battery is the device that stores energy and supplies it to the built-in processor and built-in internal memory to allow them to function as stated in the respective sections above.

Figure 6 shows a prepaid water meter with its components

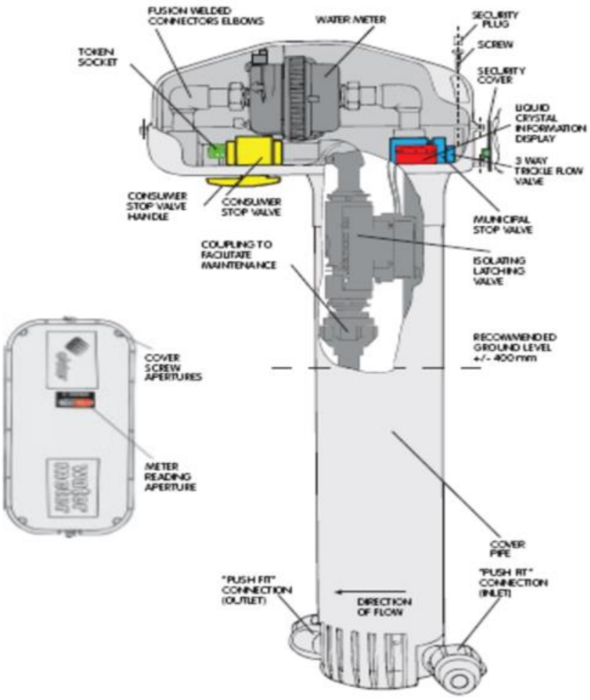

Figure 6: Prepaid water meter

Domestic prepaid meters are available as an open architecture system and a proprietary token-based system.

Open architecture system-: is the system that is compliant to Standard Transfer Systems (STS) standards. These are protocols that were developed for prepaid electricity but then prepaid water uses the very same system. With this kind of systems, a municipality can purchase products from any other manufacturer whose products conform to the same specifications, in case the manufacturer is unable to provide the goods or service (STS Association, 2016). Furthermore, with this type of products, there are multiple vending options available.

Proprietary token based system-: is the system that uses metal buttons with non-volatile memory that store encrypted data and are programmed for use with a particular meter. With these systems the goods are manufacturer specific and cannot be used with goods from different manufacturers.

2.3.2. Application of prepaid water meters

The built-in processor and shut-off valve make prepaid metering systems capable of more advanced functionalities as compared to conventional meters. They can, for instance, be used to automatically dispense the free basic allowance of water before requiring credit to operate. Alternatively, the meter may switch from a full supply to a reduced flow through the meter once credit runs out, instead of shutting down completely. Prepaid meters can also be programmed to allow users to provide some quantity of water past the point where the available credit has been depleted with a warning given to the consumer to recharge the meter credit.

Prepaid meters can also be used for batching (Malete, 2010). This is another controlled system which limits the amount of water usage per day. When the user reaches for example the 200 litres stipulated by the municipality, the valve will shut off the water supply up to a set period. With this system, users are not billed for water but the municipality controls the amount given to each household (Malete, 2010). Some municipalities prefer using daily allocation of FBW to the monthly allocation as a way to avoid wasteful use that often leads to exhaustion of Free Basic Water in the first few days of the month.

2.3.3. Technical specifications

The technical specifications for conventional meters also apply to mechanical meter components of the prepaid water metering system. Specifications in this section are as per SANS 1529-9 (SANS, 2008).

- ***Materials*-:** Standards require protection for electronic and other components of the measuring system intended for outdoor installation is durable. Whenever a metal housing is used, it is legally binding that protection against corrosion is provided.
- ***Metrology*-:** It is legally required that error the on metrological properties of a meter remain within a 3% error whenever a meter is subjected to magnetic and light influences. The SANS code also indicates that the meter may only under register by at most 5% and over register by at most 2%.
- ***Calculations*-:** The calculation error must only be due to rounding of figures. Otherwise, the metering system is regarded as non-compliant to the standards and may not be used to measure domestic consumption. The standards further require that prepayment measuring systems express the volume of water in litres and this should automatically reset to zero after credit is used up and new purchase is made.
- ***Indication of volumetric and monetary reading*-:** It is a legal requirement that the volume and monetary figures are indicated or displayed on the same indicator provided that both values are alternatively displayed at the end of a delivery with sufficient time to read these values.
- ***Memory*-:** It is a requirement that prepaid metering systems are fitted with a memory device to store measured consumption information to keep record of transactions. It is also a requirement that the memory devices, possess enough memory for any particular application.
- ***Power supply*-:** It is a requirement that prepaid metering systems have an emergency power supply to allow meters to function normally until power is restored. This is in the cases where meters operate from the principal power supply.

2.3.4. Drivers of Prepaid water metering

Prepaid water metering systems have been implemented as tools for cost recovery of water services and as tools for water demand management. However, the drivers of prepaid water metering systems over conventional water metering systems can be categorised in terms of economic efficiency, technical robustness, environmental and social benefits.

Economic aspects

The fact that the use of prepaid meters makes it possible for consumers to manage their accounts more directly, with clear knowledge of how much credit they have, makes household budgeting easier. This is opposed to the use of conventional meters that have risk of the incurring high bills and an unpleasant surprise for consumers long after consumption, leaving them in debt (Heymans, et al., 2014). Prepaid meters can therefore save consumers from wasting money and time on disputes over inaccurate bills.

For municipalities, there is a financial benefit because of no risk of arrears or debt (which might end up unpaid) for water service providers because customers pay for water in advance, facilitating better cash flow and revenue (Heymans, et al., 2014). Prepaid meters can also be used as tools to recover unpaid debts through connecting consumers who are in arrears to a prepaid meter with a portion of their arrears deducted from each credit they purchase.

With prepaid metering, the responsibility of securing access to water becomes the burden of the individual consumer and no longer that of the municipality. From an administrative point of view, municipalities save on costs as there are no meter readings, no billing statements, and no arrears and credit control. Lastly, automatic water supply cut-offs (for prepaid meters) due to non-payment eliminates the travelling costs (for municipal personnel) for manual disconnection in conventional meters.

Technical aspects

Some municipalities are driven by prestige associated with technological advances, such as smart metering and advanced metering infrastructures, as well as the increasing prevalence of prepaid systems for electricity and mobile phones (Heymans, et al., 2014). Inefficiency of conventional meters on cost recovery has driven most municipalities to resort to prepaid metering due to its added technical functionalities that are believed to facilitate better cost recovery. The functionality of self-disconnection has also played an essential role in its attractiveness.

Environmental aspects

Implementation of prepaid metering results in reduced average monthly consumption (Marah et al., 2004) as consumers become less wasteful in their water consumption. Unlike conventional metering which provides the possibility of not paying for water debt, with prepaid metering, consumers tend to ensure conservative water usage. Reduced consumption means less water has to be treated and supplied to consumers. Therefore, there is a reduction in chemicals and energy required in water treatment plants

Social aspects

Social drivers of prepaid water metering are the same as those of conventional metering as stated earlier in this chapter. No social drivers specific to prepaid water metering could be found.

2.3.5. Drawbacks of Prepaid water metering

Capital cost requirements

Capital cost requirements of prepaid meters are significantly higher than that of conventional meters. The substantial difference in cost requirements is due to the purchase price of prepaid meters and the infrastructural requirements of setting up a prepaid water metering system.

Operational requirements

Operationally, prepaid meters need close monitoring and rapid response capability to identify and resolve problems quickly due to the technological sophistication and presence of many components and additional infrastructure. Even though theoretically, meter reading is not required for prepaid metering, Heymans et al. (2014) suggests, that as part of monitoring, regular meter reading is essential to track real-time consumption against prepaid sales. The meter reading is also required to detect possible illegal connections and tampering.

Maintenance requirements

Even though prepaid metering technologies are improving, they are more vulnerable to faults and failure than conventional metering systems (Heymans et al., 2014). They are more complicated and have higher maintenance costs and a shorter average life cycle (seven years is generally the outer limit, which is half that of conventional meters). According to Malete (2010), the battery of prepaid meters lasts up to five years and then has to be replaced. Batteries fail, valve diaphragms and seals wear, moisture disrupts the circuitry, and communication errors between the credit token reader and meter can affect supply. These factors make prepaid water meter management more demanding as compared to conventional meters.

The prepaid meters have a non-return valve which shuts off the water when installed incorrectly. Another problem with installation is when the installer is working with sand and pipes while connecting a water meter box. If the pipes are not flushed, sand can enter into the water meter and cause blockages (Malete, 2010).

Municipalities have a major challenge in maintaining reliable water supply, plus managing and maintaining the interdependent electronic, mechanical and software components of prepaid meter systems at each connection site and vending point (Heymans et al., 2014). It requires a network of credit vendors selling prepaid water that must be equipped, serviced and managed. A credit transfer device is needed: either a physical token or a smartcard which can get lost, stolen or broken, or a numerical credit key, printed on paper or sent by mobile phone, and entered via a keypad that must communicate reliably with the device.

The main component of prepaid water metering is a mechanical meter, of which some of them are prone to errors caused by air and grit in the water network. This fault is common across all metering applications, but the impact is more serious in a prepaid meter. Air in the system after a supply interruption can spin the counters and erode credit, and grit can jam other meters (Heymans et al., 2014). Low water pressure can shut down prepaid water meters irrespective of whether customers have credit remaining.

Social acceptance (Heymans et al., 2014)

Installation of prepaid metering results in rising block tariffs and greater awareness among consumers of what they pay and what they get; this can lead to discontent. Consumers who buy credit more than once a month regard water charges as inconsistent as they get less credit on subsequent purchases than on the first instance. Some consumers never understand the reality of rising block tariffs and remain dissatisfied with the system.

Due to inadequate understanding of the operational and maintenance requirements of prepaid water meters, technical failures are inevitable, making meters unreliable. Unreliable meters invite vandalism, bypassing and tampering. Customers who have paid in advance for their water have a legitimate expectation that it will be available and that any faults will be repaired swiftly. Prepaid water metering systems may result in intolerance from consumers.

Lack of industry-wide standards (Heymans et al., 2014)

Most prepaid water systems use proprietary hardware and software, and municipalities may find themselves locked into a technology that is relatively inflexible and expensive to maintain and change. If municipalities are not satisfied with the performance of their systems, it is often hard to invest in additional vending sites. This only leaves them with the option to move on and try another make of prepaid meter in a new area, and set up a new proprietary vending system to serve new customers there.

Where municipalities stipulate that their suppliers must comply with the non-proprietary Standard Transfer System (STS) specifications developed for prepaid electricity there is a high chance of substantially reducing the cost of vending infrastructure and offering customers the convenience they want. STS is an open standard that defines encryption protocols for credit transfer and decoding protocols for prepaid meters so that the credit data is interpreted correctly and the meter functions as required.

2.3.6. Prepaid metering in communities

Even though the installation of prepaid water meters increases social inequalities, the motivation for their installation is their potential as an effective tool to manage consumption while maintaining a high level of hygiene and dealing with the problem of non-payment (McDonald & Pape, 2002). However, Marah et al. (2004) maintain that the benefits of prepaid metering lie less with the revenue earned than with the volume of water wasted. This makes prepaid metering more beneficial to municipalities than to communities.

A fundamental danger associated with prepaid meters is that they are intended to serve as a means of replacing termination procedures governed by existing regulatory frameworks (Marah et al., 2004). This makes poor communities sensitive to the impact of the meters and therefore may develop their negative perception towards water meters.

Negative impacts of prepaid water metering

Prepaid water meters negatively impact in a number of ways on the lives of low-income communities when installed there. The self-disconnection functionality of prepaid meters leads to undesirable situation where consumers can stay for long hours without water. Consumers can stay without water because credit got exhausted anytime outside trading hours of vending stations (night or weekends) leading to unhygienic practices such as not bathing, washing dishes, cleaning and flushing toilets (Hellberg, 2005). This unhygienic practices may be common in low-income communities where people can hardly afford to pay for water but their household consumption exceeds the free basic allocation.

Water consumption restriction

Prepaid water meter systems are made financially sustainable through the use of the progressive block tariffs where low consumption is effectively subsidised by high consumption (which earns a higher charge) (McDonald & Pape, 2002). This makes the water consumption in excess of the 6kl free basic allocation, unaffordable for most households in low-income communities. The block tariff restricts households to 6kl free basic allocation which is not adequate for most households, particularly for large households. Restriction to the free basic allocation makes special events, such as community gatherings, for festive events and rituals unfeasible.

Hygiene and safety

Technical problems and the exhaustion of free basic water allocation lead to a lack of water supply in most low-income households. As a result, many households are in desperate need of more water and thus resort to the traditional unpurified water sources, rivers and streams. In Mandlebe, Kwazulu Natal, this situation led to a cholera outbreak in August 2000 (McDonald & Pape, 2002). According to McDonald and Pape, the problem was the length of time it took for service providers to attend to the problems (McDonald & Pape, 2002). Provision of a backup or alternative water supply such as boreholes and tanks would have prevented the crisis.

Public resistance

As stated earlier in the chapter, the decision to install prepaid water meters rests largely on expectations and needs of municipalities rather than on the demands of consumers (Marah, et al., 2004). Most municipalities claim to have involved communities before implementation and indicate that consumers are satisfied with installations (Thompson et al., 2013).

There is a high rate of disconnection due to the exhaustion of free basic water allocation by households, and illegal reconnection of water tends to be a strategy adopted by activists in South Africa (Bond & Dugard, 2008). Illegal connections could be considered a better option for consumers as they are aware of the health risk of resorting to other water sources. Also, due to the common delay of water service providers in attending to problems, people tamper with prepaid water meters and in some cases resort to removing or breaking them (McDonald & Pape, 2002). The theft of water has resulted in water service providers losing revenue because of leaks from illegal connections.

2.3.7. Case studies: Implementation of advanced metering in low income areas

This section summarises case studies of prepaid metering and WMDs projects in low income areas of South Africa. For each case study, the background of the study area, reasons behind the implementation of the metering technology, impacts of the metering system and the extent of community involvement are discussed. These case studies are chosen because they are most applicable to this study (they explain the implementation of advanced metering technology in low income communities and give an indication of how advanced metering technology works and performs in low income communities).

The information on most case studies was obtained from a study conducted by Marah et al., (2004). Efforts to obtain update on the current state of the case studies was fruitless. Hence the information and facts cannot be assumed to have not changed, rather this can be treated as historic information on implementation of advanced water metering technology in low income communities. However, the relevance for these case studies is that they premise the context in which advanced meters were implemented, and may serve a benchmark against which advanced meters may be assessed.

Beaufort West Prepaid metering

Background

The Beaufort West Municipality is on the N1 route from Cape Town to Johannesburg in the Great Karoo, approximately 500 km north east of Cape Town. There is a total number of about 9 000 households in the Beaufort West municipal area, about 80% of these are in urban and the remaining 20% in rural areas (IDP, 2011).

According to the Integrated Development Plan (2012), Beaufort West has an unemployment rate of 35% with the majority of households (65%) relying on an income of between R4 800 and R38 400 per year. Of all the households, 7% have no income while 6% earn R400 per month. Beaufort West therefore is a poor community with a 50% indigence level and a low-income area (IDP, 2011).

Reasons behind the implementation

As has occurred in many South African towns, cost recovery for the provision of water services has been a problem for Beaufort West, mostly because of poverty (Marah et al., 2004). An escalation of this situation led to the municipality installing prepaid meters. The implementation of prepaid water metering is said to have started as a small experiment as part of a new subsidised RDP housing scheme in 2004, and 300 prepaid water meters were installed (Marah, et al., 2004). According to the cost recovery study conducted by Marah et al. (2004), the municipality did not have to incur any investment cost, except for the installation of a number of meters in the existing houses of the people who could not afford installation cost and had a very poor payment rate for water services.

The supplier of prepaid water meters was a company called Bambamanzi/Conlog, which assisted the municipality in setting up a small workshop regarding minor repairs to the meters.

The consumers who moved into the subsidised houses with the prepaid water meters generally moved from a situation of no payment to one of payment. The benefit which they experienced was receiving a subsidised house with prepaid water and electricity meters.

Impact of metering system

The implementation of the prepaid metering system resulted in an improved cost recovery rate. However, minor teething problems with the meters were experienced, Conlog repaired and upgraded these at their own cost (Marah et al., 2004). This was a benefit for the municipality as no additional costs were incurred for the emerging meter problems and faults.

The introduction of the Free Basic Water policy in 2000 had an effect on consumer benefits because before the installation of prepaid meters, consumers who did not pay for water were under the false impression that water was free (Marah et al., 2004) and thus did not pay for the water they used. However, this was merely deferred payment since they built up service fees which had to be paid afterwards. The installation of prepaid meters enforced payment for water, so the Free Basic Water policy exempted consumers who had prepaid meters and kept their consumption within the free basic allocation.

The study revealed that the scheme worked well until the municipality had to start paying for meters in need of repair. The maintenance cost of the scheme was higher than expected and the municipality decided to terminate the installation of new meters and the repair of faulty ones; these were simply replaced with conventional meters and the consumers were billed (Marah et al., 2004). At the end of 2003 there were still about 1 000 meters in operation, with the number gradually decreasing. The implementation of prepaid water meters therefore proved to be an unsuccessful initiative for the municipality as it resulted in loss of capital expenditure on prepaid meters.

According to Marah et al., (2004), the schemes initially worked well, but the municipality had wrongly anticipated that the Free Basic Water policy would remove the need for prepaid meters for the poor. In addition, payment for the repair of faulty meters made it less economical to keep them in operation (Marah et al., 2004).

Community involvement

The study indicates that the amount of public involvement preceding the installation of the prepaid meters was minimal (Marah et al., 2004). No incidents of either vandalism or public protests are reported in the study.

Letsemeng Prepaid metering

Background

The Letsemeng Municipality is situated in the south west of the Free State province. It comprises six towns, namely; Koffiefontein, Petrusburg, Jacobstal, Oppermansgronde, Luckhoff and Farmland, covering an area of about 10 000 km^2 and a population of 38 000 (8 000 households) in 2003, more than a quarter of whom are rural dwellers (Marah, et al., 2004). Prepaid water meters were installed in Oppermansgronde, the main town with the largest economy due to an adjacent diamond mine.

According to the Letsemeng Municipality (IDP, 2014), 10% of households in the Letsemeng Municipal falls within the "no income" category. Of concern is that of all the households in Letsemeng, 7% have an annual income of less than R 10 000 and 24% less than R20 000 (IDP, 2014).

Reasons behind the implementation

The study indicates that the Letsemeng Municipality experienced a poor and slowly diminishing rate of payment for water services in the early 1990s, with the rate as poor as 1% in 1994 (Marah, et al., 2004). This resulted in the municipality deciding to install prepaid water meters in an attempt to solve the problem.

According to the study by Marah et al. (2004), the Letsemeng Municipality entered into an agreement with Bambamanzi and in 2000 invested about R1m in a scheme in which about 1 000 meters were installed. The installation was mainly amongst the poor who happened to be the worst payers.

Impact of the metering system

The study reveals that consumers benefited from the introduction of the Free Basic Water policy in 2000, which was facilitated by prepaid meters. The allocation of Free Basic Water through the prepaid meter installation arrangement covered consumers who had received prepaid meters in the previous two years (Marah, et al., 2004). The benefit to the consumers was that they no longer had to pay for their first 6kl of water per month, resulting in a cost saving of about R 15 /month at that time.

As indicated in the study, the installation of prepaid meters was followed by technical difficulties with some of the meters. However, Bambamanzi/Conlog repaired and upgraded them free of charge and the scheme worked well, resulting in improved revenue collection. The water delivered through the prepaid meters never exceeded 6 kl (Marah et al., 2004). This showed that most consumers kept their consumption within the free basic allocation. This is quite unusual as the FBW is typically not adequate for household consumption in most municipalities. This shows installation of prepaid meters can help limit consumers to their free basic allocation without forcing them to resort to other sources of water and illegal consumption.

Since consumers kept their monthly consumption within the free basic allocation, cost recovery became a serious problem for the municipality. In 2000, Conlog was taken over by Schneider Electrical and the municipality now had to pay for all repairs (Marah et al., 2004). According to the study, at that stage the municipality only had 7% of its operating budget available for all maintenance and debt servicing (Marah et al., 2004). It then decided to no longer have prepaid meters repaired, but to replace them with conventional meters and resort back to a billing system. In 2003, there were only about 200 prepaid meters left in operation .

According to Marah et al., (2004), the Letsemeng Municipality embarked on the prepaid metering system with too many expectations and without foreseeing maintenance costs and therefore did not have adequate budget for the costs. The municipality was also not aware of the impact the introduction of Free Basic Water would have on the prepaid metering system.

Community involvement

The study reveals that hardly any public participation preceded the installation of the first meters (Marah et al., 2004), and as consumers had to switch from a non-payment situation (refusal to pay issued bills) to one of payment, some resistance was experienced when some consumers removed, returned and in some cases damaged their meters.

Nkomazi Prepaid metering

Background

The Nkomazi Municipality is located approximately 350km east of Gauteng and consists of a wedge of land between the Kruger National Park (north), Mozambique (east), Swaziland (south) and the Hlambela and Umjindi Municipal areas (west) (Marah, et al., 2004). It has a population of about 430 500 and consists of a combination of five local councils, namely Malelane, Komatiport, Marioth Park, Nkomazi East and Nkomazi West.

Reasons behind the implementation

The cost recovery study conducted by Marah et al. (2004) indicated that the Nkomazi Municipality was in serious need for a more effective revenue management system than the existing one in the area called Kamslushwa (Marah et al, 2004). Initially a flat rate of R50 a month, irrespective of the amount of water consumed, was paid by customers but this proved to be unaffordable for most. After a service audit, it was concluded that there was a need for an alternative and a more affordable technical option.

In a search for a more affordable technical solution, the majority of residents supported prepaid meters, and the municipality implemented the prepaid metering system involving about 1 370 meters. These meters were installed in houses occupied mainly by people employed in the public service.

Impact of metering system

The first batch of prepaid meters experienced teething problems because the technology was relatively new at the time (Marah et al., 2004). By 2003, four different versions of water meters had been introduced in response to various technological problems being experienced. The latest version included a new valve, locally manufactured by Schneider Electrical (previously Conlog) in Durban. Marah et al. (2004) reported that according to the technical department of the Municipality, about 40% of the installed prepaid meters were faulty due to technical failure.

The study shows, however, that the installation of prepaid water meters in Kamhlushwa resulted in a substantial reduction in the average amount of water consumed by each household from approximately 40kl per household to less than 7kl (Marah, et al., 2004). This has in some ways resulted in a more reliable water service. It is important to note, however, that the Free Basic Water policy had not yet been introduced at the time of the study.

According to the findings of the study, the financial turnaround was very significant, with an annual loss of approximately R540 000 being reversed to an average income gain of approximately R320 000 (Marah, et al., 2004). This has been attributed by officials to the outsourcing of its revenue management, with the municipality only providing technical support.

Community Involvement

Representative structures within the community of Kamhlusha were involved at all stages of the project and the installation of prepaid meters was only done after 90% of the residents supported the initiative (Marah et al., 2004).

Residents were at the centre of extensive liaison programmes and appointed local people to manage the customer care office, thus locating the process of revenue collection inside the community (Marah et al., 2004).

Polokwane prepaid metering

Background

The Polokwane Municipality includes two areas, namely the established towns of Pietersburg and Seshego, and the less developed rural areas consisting of 145 villages which are being served by Lepelle Water (Marah et al., 2004).

Reasons behind the implementation

According to the study conducted by Marah et al. (2004), effective water delivery services and cost recovery were not the main focus points for the installation and operation of prepaid water meters in Polokwane Municipality, but the urgency of getting water to each village was the driving force behind Lepelle's operations and the DWAF was providing substantial subsidisation in this regard (Marah et al., 2004). It is not clear why prepaid meter were selected as opposed to conventional meters or other types of advanced metering technologies.

Impact of metering system

The study reveals that Lepelle has been using Teqnovo water meters, but it appears that these meters, especially the PC boards, were not robust enough for the often rough handling and continuous operation of communal street taps. Maintenance costs escalated to an unacceptable level due to faulty meters, the guarantees of which had expired. So, they were eventually replaced with conventional meters (Marah et al., 2004).

Consumer benefits from the installation of prepayment water meters, which were mainly communal street taps, were varied. For many consumers, the mere fact of having a tap within 200 meters was a benefit; for others, the increased fairness of getting what they paid for was a benefit compared to the previous flat rate system where topography advantaged some consumers located down the hill (Marah et al., 2004).

It was generally found that consumers were still not willing to pay for water after installation of prepaid meters, despite the fact that the Free Basic Water policy had not yet been introduced in this municipal area.

<u>Community Involvement</u>

Since the establishment of the Polokwane Municipality in 2000, public participation has been intensified through the offices of the mayor and the relevant councillors (Marah et al., 2004). According to the findings of the study, there were no protests against the prepaid water meters.

Umzimvubu prepaid metering

<u>Background</u>

The Umzimvubu Municipality is situated within the Alfred Nzo District Municipality in the north-western part of the Eastern Cape, adjoining Lesotho to the west, KwaZulu Natal to the north and the O.R. Tambo District Municipality from the east to the south. The Umzimvubu Municipality consists of the following districts: Mount Ayliff, Mount Frere, Maluti and a portion of Mount Fletcher (Marah et al., 2004).

<u>Reasons behind the implementation</u>

The study conducted by Marah et al. (2004) indicates that the major problem faced by this municipality was the collection of income from the major sources of revenue. The municipality carried forward the debts from the former Mount Frere and Mount Ayliff Transitional Local

Councils. Collection levels were then at approximately 30% of actual amounts billed on a monthly basis. One of the problems that pushed the prepaid metering project was that revenue collection was necessary but difficult due to the absence of water meters on most properties. The Masakala project was implemented as an attempt to address this imbalance in revenue collection in the periphery of Matatiele. The Masakala project was a pilot project to investigate the suitability of prepaid meter technology for water supply in rural settings (Marah et al., 2004). These villages had a total population of about 1 000 families, the majority of whom were poor, living on welfare pensions (an average of R550 per month). The water committee decided on prepaid metering as a possible option and requested Bambamanzi and TeqNovo to demonstrate their units to the community. The community strongly backed the committee's initial decision to install prepaid water meters because they saw it as fair way of charging for water whilst providing a 24-hour service. The committee selected the more expensive TeqNovo units because of their robust, refined appearance and long-life battery system.

Impact of metering system

The study conducted by Marah et al. (2004) indicated that the project was plagued by numerous problems, ranging from poor design of the prepaid meter to incompetence of the operators (Marah et al., 2004). As a result of this and the fact that suppliers provided very little support to the team managing the system, a number of prepaid meters and communal taps did not function properly.

According to Marah et al. (2004), the main problem was the local municipality's lack of capacity. Critical support and training of local support staff by the manufacturing firm of the system was necessary for sustainability, but the training provided was not sufficient or sustained (Marah, et al., 2004). Further, many of the consumers had access to alternative sources of water (Marah, et al., 2004) which they used instead of paying for water through prepaid meters, therefore revenue collection was minimal.

Community involvement

The Masakala Village Water Committee (VWC) was fully involved in all aspects of the project, including project planning, construction, administration and financial management processes (Marah et al., 2004). The committee acted as the client and was directly responsible for all project procurement, assisted and guided by the Mvula Trust.

The water committee handled and managed all conflicts and was delegated responsibility to employ and supervise staff in addition to managing and operating the water supply scheme.

Mogale prepaid metering

<u>Background</u>

Mogale City is situated to the west of Johannesburg in Gauteng Province and is accessible from other major centres such as Pretoria and Sedibeng. Previously known as the Krugersdorp Local Council, Mogale City is named after Chief Mogale-Wa-Mogale. The main locations in the municipality are Krugersdorp, Kagiso, Magaliesburg, Munsieville and Muldersdrift. Mogale City is a mixture of urban and rural areas with some very varied demographic characteristics, hosting a population of about 300 000 people (Marah et al., 2004).

The urban areas show different levels of development in terms of population income levels. The former black townships are a mixture of clearly laid out sections and dense pockets of informal settlements (Marah et al., 2004). The formal township is divided into old sections with houses and many shacks in the yards and recently developed sections (less than 15 years old) with the original formal structures but no backyard dwellings.

<u>Reasons behind the implementation</u>

The cost recovery study done by Marah et al. (2004) indicates that before the merging of different areas into the Mogale City Municipality, payment levels for water services in the predominately black areas were very low and on average only 8% (Marah et al., 2004). The main reasons for these low levels of payment were unwillingness to pay, inability to pay, non-billing of consumers due to the absence of meters, inefficient billing of consumers due to inadequate technology, and human error and lack of proper accounting by water service providers (Marah et al., 2004). These were the problems that led to the installation of prepaid water meters.

The same study by Marah et al. also shows that after the merging of small townships into Krugersdorp in 1994, the number of water connections increased from 17 000 to 40 000. The water service network had to be upgraded to acceptable levels, so huge amounts of capital investment were required. To raise this capital, prepaid meters were installed to increase revenue from municipal water, and as a result 11 000 prepaid meters were installed.

Impact of metering system

The study describes the project as a success to both the municipality and water consumers because it resulted in increased revenue which was then used to finance the infrastructure upgrade.

Community involvement

According to the findings of the study, in January 1998, an investigation into the use of prepaid meters was carried out. The investigation included a debate in the community on many issues before the project was commenced. The study also shows that in spite of what was, at that stage, considered to be full consultation with the community, the matter was further delayed when community representatives objected on the grounds of insufficient consultation in about October that year (Marah et al., 2004). Further community consultation took another three months, but in January 1999 the first of 16 500 new prepaid meters were installed

The municipality set up a policy relating to prepaid meter systems (Marah et al., 2004). According to the policy, all new water connections automatically received a prepaid water meter without the consent of the property owner, while for existing consumers with formal connections, it was optional to apply for a prepaid meter, retrofitting was done free of charge and meters were installed inside the properties to encourage ownership and prevent vandalism. Furthermore, the capital cost of the installation was subsidised by the council, there was no mark-up to the cost of water supplied, and the tariffs applied were the same as for conventional meters (Marah, et al., 2004). Local community members were employed to carry out basic plumbing and retrofitting.

Klipheuwel prepaid metering pilot project

A pre-paid water metering pilot study was implemented in Klipheuwel, Cape Town, in 2001. This was done mainly to assess the capability of prepaid water meters to improve the management of water service delivery in the Cape Metropolitan area (Kumwenda, 2006), but the project was not successful and therefore abandoned.

The study was conducted in Klipheuwel, a low-income area comprising of both informal and formal settlements, but it was focused mainly on the formal settlement (Kumwenda, 2006). The study was done on 147 houses occupied mainly by coloured working class people, with a number of black households. In the study, pre-paid water meters were installed in 138 households, with the meters programmed to dispense 6 Kl per month, this being the free monthly allocation per household. An additional 200 litres of water was also allowed for emergency purposes, and the rest could be purchased.

Due to high failure rate of meters, the pilot project was considered to have failed. After failure of the pilot project, prepaid water meters were replaced by conventional water meters, with a free 6 kilolitres allocation and then a block tariff to discourage high consumption (Kumwenda, 2006). This is one of the few case studies in the literature that is documented as 'failed'. In the study, a questionnaire was used to collect qualitative data from the 138 households with prepaid water meters. The intention of the study was to establish consumer perceptions of prepaid meters, more especially in incidents where implementation was a failure.

The study revealed that most of the households (66.7%) in Klipheuwel considered using a prepaid water meter *very important*, while 25.9% felt it was *important*. Thus, 92.6% of the users were certain that using a prepaid water meter was important to them (Kumwenda, 2006). Only 1.2% ranked using prepaid water meters to be *moderately important* while another 1.2% ranked it to be of *little importance* and the remaining 4.9% did not *consider it important* to them (Kumwenda, 2006). The responses from the survey showed that water users had a positive attitude towards prepaid water meters as they empowered them to budget and manage their water consumption. Prepaid water meters were also convenient as there was a vending shop close by. The study revealed that consumers were more comfortable with prepaid meters than with conventional water meters.

Installation of Water Management Devices (WMDs) in Cape Town and EThekwini

Water Management Devices (WMDs) are one of the technologies believed to bring a solution to water demand management problems and cost recovery problems in low income communities. Installation of WMDs in Cape Town and EThekwini are one of the biggest WMDs systems in South Africa. Selection of this two Metro Municipalities in this study gives a broad outlook of these systems within a South African municipality. One other reason for choosing these two metro-municipalities in this study is their similar reason for implementation, which are: charging viable user fees, enabling users to conserve water, managing consumer debt and providing FBW.

Regarding the implementation of WMDs, Thompson et al. (2013) conducted a study using surveys n selected areas to determine user perceptions regarding the usefulness of WMDs.

Selected study sites were Saxonsea and Samora Machel in Cape Town as well as Umlazi and Umbumbulu in eThekwini. The selection of case studies was carefully done in order to provide a broad range of low income communities that were affected by the installation of WMDs.

According to the findings of Thompson et al., (2013)'s study, there were perceptions expressed that the implementation strategy tended to either exclude users or were carried out through manipulation. This is considered poor community participation. Consumers were convinced to accept the installation of WMDs by receiving benefits such as, an onsite tap was given to consumers who decided to accept the installation. However, the study still indicates that users were satisfied with the implementation of the technology as they no longer had to worry about debts and possible water disconnections because either the free basic water was adequate for household requirements or water consumption was now properly managed to meet household requirements. Consumers satisfaction was achieved because beneficiaries could reduce their expenditure of water as their consumption was reduced after installation of WMDs. Furthermore, the study shows that reduction in consumption in some cases resulted from consumers making an effort to remain within the free basic water limit. Some of the efforts, however, had significant negative effects on health and hygiene. Detailed results of the sites selected in the study are outlined in the respective subsections below.

Saxonsea

The study reports that Saxonsea is a low income settlement with a total population of approximately 132 828, with 5.3 people per plot and 4.77 people per household (Thompson et al., 2013). Residents of Saxonsea all qualified for the Free Basic Water (FBW) allocation of 6000 litres per plot per month. The study revealed that with the implementation of WMDs, 24% of the households ran out of their daily allocation of water. The FBW was allocated on a daily basis so as to make the allocation easier to manage as some municipalities believe that it is better to manage the allocation if it is made on daily basis. The installation of WMDs was helpful to the 24% that ran out of their daily allocation as those were the only households battling with water demand management.

The study also established the level of satisfaction of the residents through interviews.

The study showed that the level of satisfaction with WMDs in the Saxonsea community was as follows: 49.1 per cent of the respondents were satisfied with the implementation of WMDs while 11.7 per cent of the respondents were not satisfied with the implementation of WMDs.

The study further revealed that 14 per cent perceived conventional water metering to be much better than WMDs.

The study showed that 22 per cent of the households had experienced problems with the WMD, of which 9 per cent experienced these problems frequently (i.e. a few times a week or daily) while 78 per cent indicated that they had not experienced any problems (Thompson et al., 2013). Problems experienced were technical failure of the WMDs, water leaks on the meter and unanticipated discontinuation of supplies.

At community level, 72 per cent of the respondents indicated that they were not aware whether the City had consulted with the community about the new water access restrictions and the WMDs through public meetings, while 17 per cent indicated that no meetings were held and 11 per cent said the City had held meetings (Thompson et al., 2013). At individual household level, 43 per cent of the survey respondents said they were consulted in some way before WMDs were installed, whilst 57 per cent claim that they were never consulted. It is not quite clear how the consultation was carried out and whether people might have been made aware of the implementation but not necessarily involved in the decision making process.

Figure 7 shows the level of satisfaction of the Saxonsea households:

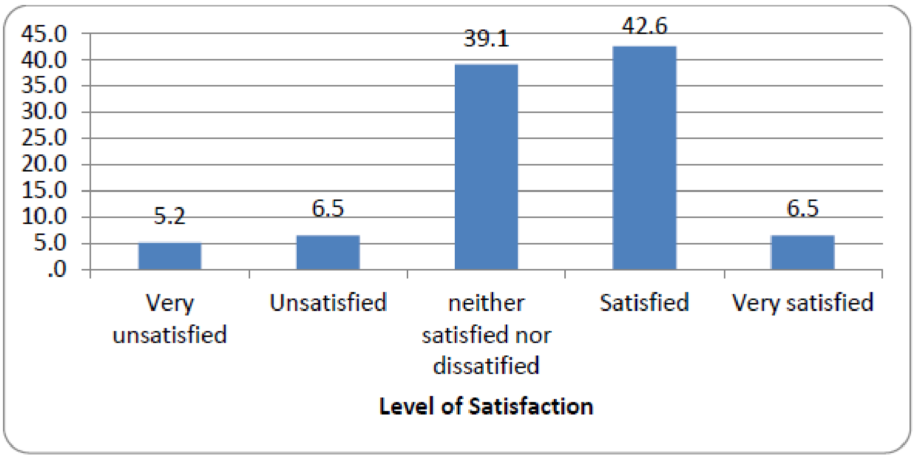

Figure 7: Level of satisfaction of Saxonsea community with WMDs (Thompson et al.,2013)

Samora Machel

Samora Machel is an informal settlement characterised by dense concentration of shacks (Thompson et al., 2013). According to the study, Samora Machel consists of 4 860 metered connections and a population of 35 915 people with an average of 7.39 people per stand. For the study, Samora Machel was divided into backyard dwellings and the main dwellings. The mean household size for backyard dwellings is 3.75 while that of main dwellings is 4.41 (Thompson et al., 2013).

In Samora Machel, 90 per cent of the respondents in main dwellings indicated that they had not been consulted about the project and 10 per cent indicated that they had (8 per cent of whom found the consultation process informative) (Thompson et al., 2013). It is not clear at what stage of the project and what level of participation the residents were involved in, but it is reasonable to infer that residents were made aware of the project rather than involved in the decision making.

The study found that 42 per cent of the respondents from backyard dwellings exceeded their daily allocation compared to 33 per cent of respondents from the main dwellings (Thompson et al., 2013). This difference could be due to occupants of backyard dwellings being more active working people with a more water demanding lifestyle. The difference could have been much higher but since people are working and do not stay at home, it came out as low as reported.

As per the study, residents of Samora Machel were generally satisfied with WMDs, with 65 per cent of the main dwellings respondents and 59 per cent backyard dwellings being satisfied, while 38 per cent of backyard dwellers and 32 per cent of main dwelling respondents were not satisfied (Thompson et al., 2013).

The study reported that 20 per cent of the main dwelling respondents and 24 per cent of the backyard dwellings indicated that they had experienced technical problems with the WMDs such as malfunctioning of the WMDs and frequent cut-offs (Thompson et al., 2013). This could be as a result of exceeding daily water allocations and leakage.

Figure 8 shows the satisfaction levels of Samora Machel residents:

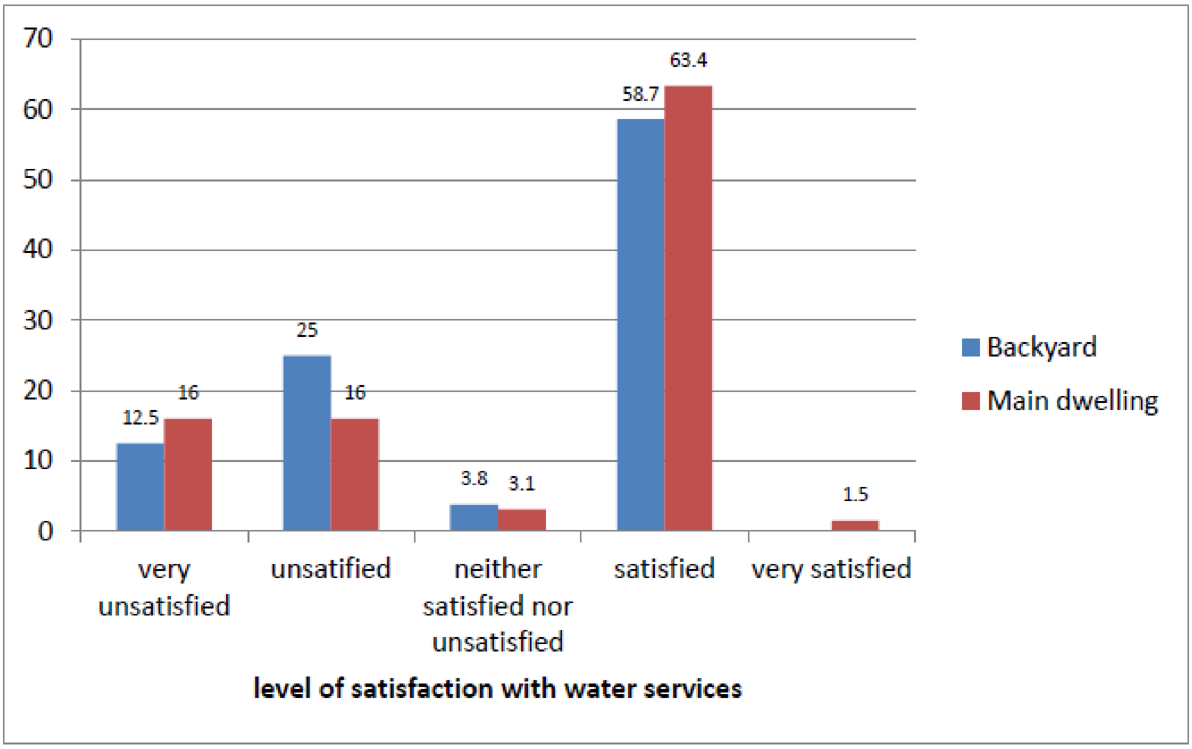

Figure 8: Satisfaction levels for Samora Machel residents (Thompson et al., 2013)

Umlazi

Umlazi is an outlaying residential area consisting of a combination of low income and high income formal housing, but with the majority being low income (Thompson et al., 2013). The suburb had a population of 550 000, making it one of the largest suburbs in South Africa. According to the WMDs study, 96 per cent of the households have eight people or less. It was also established from the study that the suburb has a mean of 4.75 people per household, implying that each person has 63.16 litres per day which is more than double the free basic allocation of 25 litres per person (Thompson et al., 2013)

In Umlazi, residents had to apply for the installation of WMDs to limit their water consumption to free allocation (Thompson et al., 2013), and according to the study it was found that after implementation of WMDs, 22 per cent of the households ran out of their daily allocation while 78 per cent did not. It was further established that consumption depended on both family size and composition; most families composed mostly of children ran out of the daily allocation.

According to the study, 92 per cent of the residents were satisfied with WMDs and confirmed that this saved them from paying high bills and enabled them to control their consumption and not to exceed the daily allocation (Thompson et al., 2013). However, high levels of satisfaction could have been caused by a 'bias' in the sample since the installation of WMDs was voluntary in this case. Beneficial as the WMDs could be, water still remains a basic need and the question remains how the 22 percent of people cope without water after their daily allocation is exceeded.

Satisfaction does not really indicate absence of problems or challenges but rather belief that the benefits are greater. Satisfied as the residents were, the study revealed that 15 per cent of the residents experienced one or more of the following challenges with WMDs (Hellberg, 2005):

- flow limiters not dispensing water,
- flow limiters could dispense less water than the daily allocation
- flow limiter could dispense more water than the daily allocation.

With the above problems, WMDs could be regarded as a failure if they fail completely to meet the purpose of their installation or if these problems occur frequently.

Umbumbulu

Umbumbulu is a rural area consisting mainly of low income houses (Thompson et al., 2013) with 8.04 people per household on average.

The study reveals that 82 per cent of the households were consulted for the implementation of WMDs (Thompson et al., 2013), but the study does not reveal to what level of participation or stage of implementation residents were involved. The study also reveals that WMDs were installed in Umbumbulu as part of the transition from communal taps to onsite water supply and every household with onsite water supply had WMDs installed. Residents' satisfaction was therefore less about the implementation of WMDs than about the installation of onsite water supply. In this area exhaustion of daily allocation still remained a problem. It is normal for consumers to increase their consumption as they move from communal stand pipes to onsite water supply. This is because of the element of luxury that comes with convenience of having a water tap in the yard as compared to the burden of carrying water from the communal tap to the house.

Operation Gcinamanzi in Soweto

Background

Operation Gcinmanzi is a project that was implemented in Soweto to address water conservation problems. The installation and operation of prepayment water meters was one of the measures taken (Singh & Xaba, 2006). As the largest water prepayment project in South Africa and Africa as a whole, the project comprised of 57 000 prepaid meters installed in Johannesburg (Soweto) and 10 000 meters installed in Mogale City.

Reasons behind the implementation

The project was implemented to address the problem of high volume NRW. The municipality was pumping 60kl of water to each household yet only 20kl was billed at the flat rate, leaving 40kl per household as NRW (Singh & Xaba, 2006). To solve this problem, the municipality installed prepaid water meters, and to achieve the required objectives, the meters were programmed to perform the following:

- dispense 6000 litres of free allocation, beyond which water credits were to be purchased
- detect leaks and show the leak on the display screen
- show the amount of water credits
- carry over the purchased credits to the next month until consumed.

Impact of water metering

The anticipated impact of the implementation as calculated over a period of five years indicated that the municipality would raise enough income to overhaul water distribution infrastructure as well as making a profit on top of that (Singh & Xaba, 2006). However, that was not the reality as most of the households could not afford to pay for consumption and rather limited their consumption to FBW. However, limiting household consumption to FBW water proved to be a problem since 6kl per month was not adequate in many cases. The reason for this was that FBW calculation had been done per erf and not per household (Singh & Xaba, 2006). The resulting misapplication of FBW policy resulted in serious social consequences as up to 22 people could be found on a single erf, meaning that each person would have to live on about 9 litres per day as opposed to 25 litres per person per day (the figure that was used for the calculation of 6kl per month per household) (Singh & Xaba, 2006).

The results revealed that supply in Soweto and Mogale has dropped from 66.7 kilolitres per month per stand to about 11.43 kilolitres per month per stand representing a reduction of 83 percent in bulk water saving (Singh & Xaba, 2006). It was also found that 46 percent of customers used more than 6 kilolitres per month and were topping it up with R22 per month.

According to the Anti-Privatisation Forum (a community organisation addressing local water and electricity crises), the outcomes of the installation resulted in the following problems (Coalition Against Water Privatisation, 2004):

- increased stress and tension within households
- restricting water usage to cover basic needs prevented residents from running small businesses that require water use
- cultural ceremonies that required water usage suffered
- coping strategies to save water resulted in unhygienic conditions.

Due to the social problems that arose from implementation of prepaid meters, the residents challenged the policy and the lawfulness of the installation.

Community involvement

In order to persuade consumers to have prepaid meters installed, consumers were offered an incentive that their already existing debt would be written off if they chose to install water meters. However, the results of the Anti-Privatisation Forum indicated that 68 per cent of the residents felt that they had not been given a fair choice of whether to have prepaid meters installed or not.

2.3.8. Trends and lessons to be learn on prepaid metering case studies in low income communities

Cost recovery is the major reason for implementing prepaid meters. However, with the Gcinamanzi prepaid metering project, water demand management was the major reason for implementing prepaid metering in Soweto with cost recovery being the secondary reason for implementation. With Polokwane prepaid metering, there is no specific reason why prepaid meters were chosen except that consumer points had to be metered of which conventional meters could have been a better option as they are cheaper and less robust.

The implementation of prepaid water metering happened in the era where FBW water was being introduced. For all municipalities, FBW was already introduced by the time of implementation with Nkomazi and Polokwane being exceptions. If in the time of smart metering implementation, FBW was not implemented, implementation had a negative impact on cost recovery as consumers kept their consumption to FBW resulting in less revenue (if any) than expected.

The prepaid metering projects reviewed were unsuccessful with Nkomazi and Mogale being exceptions. In this study success means metering systems continued to be in operation. Poor success rate of prepaid meters was mainly due to high failure rate and high maintenance and repair costs with Gcinamanzi failure being hugely dictated by high public resistance. Even though high meter failure rate and high maintenance and repair cost were the major causes of project failures, the schemes (projects) continued to be in operation until meter suppliers stopped doing repairs at their own costs.

Despite high maintenance and repair costs, the schemes were achieving their objective of cost recovery. In Nkomazi, prior to installation of prepaid meters, the municipality was making a R 540 000 loss on water service and made R 32 000 profit after installation of prepaid meters leading to expansion of the scheme. In most schemes, FBW eroded the economic benefits of installing water meters as consumers kept consumption within FBW allocation. Bearing in mind that FBW is financed by National Treasury, if adequate budget was made for maintenance and repairs of prepaid meters, schemes could have been sustained. This failure can also be associated with municipalities' inadequate budget.

Implementation of prepaid meters has a significant impact on water consumption. In Letsemeng, consumption never exceeded 6kl per household per month after implementation of prepaid meters. In Nkomazi, consumption reduced from 40kl to 7kl per household per month and in Soweto (Gcinamanzi), consumption reduced from 66.7kl to 11.3 kl per household per month after implementation of prepaid meters. This shows that prepaid meters are effective tools for water demand management in low income communities. This could possibly be due to income level of the community as consumers may not be able to pay for excessive consumption.

The use of prepaid meters does tend to restrict the average usage to what consumers can afford of FBW allocation, thereby having the potential to save on the amount of water to be treated and distributed to consumers and hence saving cost for the municipalities. On the one hand, restricting consumption has results in the reduction of water sales made by the municipalities.

Administration of FBW allocation seems to be inefficient. For instance, in Soweto (and possibly in the other municipalities) it was per erf and not per household. This misapplication of the FBW policy had serious social consequences given there can be more than one household on a single erf making the FBW allocation inadequate (below the minimum 25 litres per capita as prescribed by South African guidelines). This coupled with the community being accustomed to non-payment for service result in serious consequence. In Soweto, public resistance led to a court case.

Table 1 shows the comparison between prepaid water metering schemes in the above outlined low-income communities.

Table 1: Prepaid metering schemes details

	Beaufort West	Letsemeng	Nkomazi	Polokwane	Umzimvuvu	Mogale	Klipeuwel	Gcinamanzi
Year	2004	2000	2000	2003	Not Known	1999	2001	2003
Number of meters	300	900	1374	1100	80	16500	138	57000
Product	Conlog	Conlog	Conlog	Teqnovo	Teqnovo	Not known	Not Known	Elster Kent
Successful	No	No	Yes	No	No	Yes	No	No
Reasons for failure	High maintenance and repair costs	repair costs too high	40% of the meters were faulty	Meters not robust enough and Consumers were not willing to pay	Poor design of meters and inadequate training of operators	Faulty meters were regularly replaced	High failure rate	High public resistance

In failed schemes prepaid meters were replaced with conventional meters.

2.3.9. Similar Study

Preliminary feasibility study for the use of prepaid/alternative domestic metering solutions

<u>Introduction</u>

The preliminary feasibility study for the use of prepaid or alternative domestic metering solutions was conducted in eThekwini by an engineering consulting firm GIBB Consulting in 2015. The initiation of the project was based on the fact that eThekwini Municipality Water and Sanitation Department (EWS) were experiencing challenges collecting revenue for water supplied, especially to customers in low-income, rural, and informal settlements. Reasons for poor collection were cited to be as follows (GIBB, 2015):

- Many existing domestic water connections in low-income housing projects, rural and informal areas were not metered,
- Lack of formal cadastral, street addresses and/or postal services in rural and informal areas made bill delivery and payment enforcement difficult and resulted in high rates of arrears,
- Predominant culture of non-payment for water services by the indigent consumers in those areas resulting in high rate of tampering of meters and illegal connections

To address this, issue of poor revenue collection and hence cost recovery, on the behalf of EWS, GIBB Consulting looked at the feasibility of prepaid metering and any other alternative domestic metering solutions. Among the alternative metering solutions investigated were:

- Prepaid domestic connections and prepaid water dispensers
- On-site billing
- Flat rate billing linked to prepaid electricity
- Two-meter conventional system with user interface unit (herein also referred to as "enhanced conventional metering")

These potential solutions investigated in this study, were evaluated quantitatively through use of a Cost Benefit Analysis. Even though revenue collection and hence cost recovery were the main objective of implementation, the financial viability of the solutions was accompanied with a qualitative analysis on the following grounds (GIBB, 2015):

- Efficiency in addressing wise water use
- Efficiency in addressing bill delivery
- Efficiency in addressing revenue collection
- Potential for capacity building and job creation
- Technical functionality
- Socio-economic compatibility
- User-friendly operation and potential to empower consumers.

The above were used as design criteria to select the best solution for implementation and each of the technologies were tested based on the above aspects.

<u>Applicable policies in EWS</u>

The type of technology to be proposed amongst the options to be investigated had to comply or rather fit into the legislative regulation of the municipality. To determine the feasibility of the above mentioned technologies, the following policies were taken into consideration as they have a direct impact on the feasibility of technologies (GIBB, 2015):

- Free Basic Water (FBW) is available to indigent communities; the FBW allocation is 9 kiloliters per household per month
- Flow restrictors are installed where water has been unpaid for 60 days and where the amount outstanding is greater than a specified amount. Flow restrictors allow water to pass at an extremely low flow rate. If consumers are found tampering with the restricting washer on more than three occasions, then the water connection will be removed.
- Flow limiters that limit consumption to the FBW allocation may be installed where:
    - A flow restrictor has been installed, and consumers opt to have a flow limiter installed instead of pay the outstanding arrears in full
    - Consumers apply to have flow limiters installed
    - Where a consumer has signed into the debt relief programme and chooses this option or where the consumer defaults on payments under the debt.

The above mentioned policies has a potential to directly impact the rate of revenue collection as they affect the rate at which people can pay based on availability of funds and debt standing.

Method of investigation and acquisition of the relevant information

The Cost Benefit Analysis was a major approach to determine the feasibility of prepaid watering system in the eThekwini area. The analysis was made based on the following assumptions.(GIBB, 2015):

- The appraisal period is 20 years.
- The discount rate tracks inflation; both are taken to be 8%
- The annual water tariff increase for domestic use is 10%
- The annual increase in the cost of water to EWS is 8.5%
- Interest charged on arrears is 12%

For each area (high-income, middle-income or low-income), the average daily consumption was calculated from the average daily volumes over the past 12 months divided by the total household count for the area and the average daily household usage of 350 litres per household per day (GIBB, 2015). It was further highlighted that this average daily consumption slightly higher than the Free Basic Water allowance making it a non-critical aspect of the water distribution system.

The level of payment was determined through checking the billing database to see the percentage of connections which generated arears in the past 12 months and the results were as follows:

- 7.9% in high income areas
- 7.5% in middle income areas
- 9.8% in low income areas

The results reflected that non-payment was a concern in all income areas and therefore the need to investigate implementing new technologies in those areas was found. However, the intention for the municipality was to start addressing the problem in low income areas.

The number of unmetered connections was determined through GIS database and was estimated to be about 60 000 in the eThekwini Municipality. This value was said to exclude the rural areas entirely due to lack of formal cadastral maps making quantifying the number of unmetered connections almost impossible.

Based on past experience, water consumption in housing projects often reduces from 1000 to 500 litres per day once meters have been installed. This reduction amounts to 50%.

In terms of arrears, it was found that for conventional metered connections, there was an annual 28.8% growth in water arrears in low-cost housing projects, and an annual 17.6% growth in water arrears in the rural areas. This values reflect that approximately 81 700 and 11 300 connections in low-cost housing and rural areas respectively are in arrears totalling R 509 million making this a very significant problem for the municipality. It was further found that majority of consumers who are in arrears owe between R1 000 and R5 000, with reasons for non-payment being as follows (GIBB, 2015):

- Unwillingness to pay for water used
- Lack of awareness of the need to pay for water services
- Large bills that cannot be paid being generated by leaks and/or wasteful water use
- Poor bill delivery (this is more likely in rural areas).

The rate of illegal connections and tampering was deduced from The Electricity Department which had 380 000 municipal prepaid meters installed. This translated to tamper rate of 3% and was assumed for water meters.

Through consultation with water meter suppliers and different municipality personnel with the water metering technology, it was determined that the average age of conventional domestic meters in the field was 8.2 years. However Technical Customer Services aims to change meters after 10 to 15 years of service, even though some meters remain operational for 20 years. It was advised that 10 years would be a reasonable service life upon which to base financial analyses

It was also found that about a total of 43 280 meters (8.8% of the total connections) were replaced. To be conservative enough, an assumption of 8.8% per year was made.

<u>Outcomes of the study</u>

From the Cost Benefit Analysis, it was found that prepaid domestic meters have the highest Cost Benefit Analysis Ratio and Net Present Value for all the four areas. This proved prepaid domestic to be the only profitable solution over the assumed appraisal period while conventional metering showed marginal viability for previously unmetered low cost housing only (GIBB, 2015). It was also found that, flat rate billing will not be profitable due to high tamper rates.

In the study it was found that prepaid meters require more capital cost and a more frequent replacement (with an effective service life of 7 years) compared to conventional meters (which have an effective service life of 10 years). The average Net Present Value per unit of the prepaid system over 20 years was R22 300 while that of conventional system was R-15 500

3. EVALUATION FRAMEWORK

3.1. Introduction

This chapter describes the framework for evaluating advanced metering technologies in low income communities.

The chapter outlines the important parameters relevant to selection of advanced metering technologies with possible values that the parameter could bear in low income communities. The possible values of the parameters are an outcome of literature and the practitioners' survey where professionals working in the water sector were invited to participate in a survey in which the values were to be input according to their individual knowledge and experience. With diverse and widely varying values from different respondents, the typical, low and high possible values were established and hence the sensitivity analysis was carried out to check which parameters have considerable impact on the outcomes of the evaluation results.

The evaluation criteria for advanced water metering technologies are to be determined on technical, social, economic and environmental grounds; appropriate indicators are selected accordingly to assess the feasibility of implementing a particular metering technology.

This framework follows two steps:

- ***Validation***. Validation is the process of confirming that a particular water metering technology can serve as a solution to a municipality's intended objective. This process involves matching up municipal objectives to water metering technology capabilities and functionalities. In this process, technical requirements for addressing an objective are outlined; then the water utility can compare these requirements to the specifications and capabilities of particular water metering technologies to establish a matching solution to their objective.

- ***Evaluation.*** After the validation process, the municipality should be in a position to identify a range of metering technologies that can serve as potential solution for the intended objective. The identification of a range of possible appropriate technologies is then followed by a detailed evaluation of technical, social, environmental and economic factors based on selected indicators and relevant parameters. This evaluation process will identify the technology best suited to the municipality's objectives and circumstances.

3.2. Validation

3.2.1. Introduction

As mentioned in Chapter 1 and Chapter 2, many different advanced metering technologies are available on the market and new technologies are continuously being developed. In addition, each metering application is unique and it is necessary to carefully consider the purpose of an implementation before potentially suitable metering technologies can be identified.

In this section, different possible aims and objectives of implementing advanced metering technology are outlined together with technical requirements the metering technology has to possess in order to function as adequate for the intended objective. It is quite important that the objective of implementation matches the functionalities and capabilities of the metering technology to be implemented.

3.2.2. Defining objectives

It is important that the implementation of any advanced water metering project is driven by a clear definition of the project objectives that can be measured to predetermine the feasibility and success of the project. From the literature on past implementations and information on the functionalities and capabilities of advanced water metering technologies, the following were identified to be reasonable objectives for implementing advanced water metering technologies:

- ***Cost recovery*** – increasing revenue from water sales.
- ***Debt management*** – dealing with consumers with large debts or non-payment.
- ***Water demand management*** – managing the system and users to use water more efficiently.
- ***Consumer choice*** – providing consumers with alternative technologies to suit their needs.
- ***Extending the formal network*** – adding new consumers to the formal supply network.

- ***Network management*** – on-demand information on flow and demand patterns in the network.

- ***Understanding consumer behaviour*** – monitoring trends in consumer behaviour.

The above objectives are discussed in more details below, and minimum and recommended features are listed for each application.

It is important to note that all consumer water meters have to comply with the minimum standards described in SANS 1529. This is a legal requirement in South Africa for all consumer meters and thus municipalities are not allowed to consider non-compliant meters.

Cost recovery

Cost recovery is the process of recording the volumetric consumption of consumers as the basis of charging consumers for it, particularly through pre-paid dispensing where consumers pay in advance for the water they use. Alternatively, meters can provide a given level of credit before limiting the flow to the consumer. Accurately capturing the consumer consumption is of financial importance as it may result in increased potential revenue from sewage services when these are charged as percentage of water consumption.

Cost recovery is a target of municipalities whose supply system operations are mostly funded by revenue from the water supply system. Such municipalities may experience financial difficulties (collecting enough revenue to finance their required operations), if a large percentage of consumer consumption is not captured and therefore not charged.

Implementation of appropriate advanced water metering technology can be the solution to a cost recovery issue if the following capabilities and functionalities in addition to the minimum requirements are provided:

- Shut-off or flow restriction valve.

- Control system to manage the water supplied.

- Payment registration system to communicate payments to the control system.

- Ability to provide the minimum basic water allowance for consumers without credit.

- Tamper protection and alarms.

It is important that cost recovery is only implemented in areas where consumers are able and willing to pay for water and believe that it is morally the right thing to do. Technology, such as a prepaid water meter, cannot be used to force a community to pay for water they don't believe is justified.

Debt management

Debt management is the process of returning consumers with large outstanding debts due to non-payment for water services to being paying consumers. This typically involves an agreement with the consumer whereby past debt is written off if the consumer accepts the installation of a water management device and agrees to pay for future water use. In some cases a part of the debt is recovered by increasing the price of water consumed for a given period.

Debt management metering systems require the same capabilities as cost recovery systems, but may additionally require the ability to be programmed to incorporate debt repayment as well as water payments.

Water demand management

Water metering systems can play an important role in reducing wasteful consumption and on-site leakage as part of a water demand management strategy.

Water demand management is essential in areas of scarcity of water resources and where the cost of increasing water supply will be impossible or very expensive.

In areas where the municipality has to incur heavy cost for additional supply like pumping and importing water from outside the area, it is important that water demand is managed through encouraging wise water consumption and reducing leaks on consumers' properties.

Another way of managing water demand is through enforcing water use restrictions such as irrigation at certain times of the day. This could be monitored through implementing advanced metering technology that can identify types of water use that are not allowed. Time-varying water pricing may also be implemented to encourage consumers to reduce the load on the distribution system by using water in off-peak periods. Finally, a municipality may impose a hard or soft cap on the quantity of water dispensed to each consumer.

Water metering technology used for water demand management may require the following capabilities:

- Ability to detect leaks on the consumer's property.
- A system to communicate water consumption to a display in the consumer's home.
- Ability to send alarms, e.g. through email or sms, to consumers or the municipality.
- Ability to limit supply.
- Ability to monitor and enforce water restrictions or variable water tariffs.
- Indicate time of use volumes and tariff options that encourage wise water use.
- Ability to use multi-tier step tariff system to monitor the monthly consumption of the consumer and charge using appropriate tariffs.

Even though a metering technology with the above-mentioned capabilities is technically adequate as a tool for water demand management, it is also important that it is done in a way that results in minimal resistance from the public, for example not by cutting off consumers from the water supply. It is also important to assure that the community understands the importance of water conservation. For better water demand management, it is important that detection of leaks is followed by leak repair; this is mostly possible in communities that can afford to repair the leaks on their own properties. It is also most efficient in areas where the education level is adequate for consumers can interpret feedback and understand how they can act accordingly to control their consumption.

Consumer choice

Consumer choice to install advanced water metering technology is the voluntary decision of consumers to have technologies installed due to benefits that come with the technologies. Some consumers choose advanced water metering technologies because they are aware of the importance of water demand management as citizens of a water-scarce country and some choose them so that they can have control over their budget especially of water costs.

Installing advanced water metering technology to consumers who choose to have them installed has a positive impact on their satisfaction and thus willingness to pay. In communities where consumers are concerned with budgetary issues, advanced water metering technology can be installed for consumers to have control over their budget and consumption. Advanced water metering technology can assist consumers not to exceed the free basic allowance or limit the amount spent on water. Appropriate choice of water metering technology which takes into account consumer demand and needs can thus promote responsible water use and high payment rates. The metering system requirements will depend on the specific needs of the consumers.

Extending formal networks

Extending the formal networks means expanding water distribution systems to areas that were not serviced before and don't have the formal infrastructure to link consumers in a conventional way. This is a way of increasing the level of service for communities, in some cases for new developments or for new rural and informal settlements.

In some areas like informal settlements and low-income rural areas there is a poor cadastral arrangement and no addresses or stand numbers. In these cases, conventional metering may not work as there is no billing address. Installation of advanced metering technology such with onsite billing and remote reading or prepaid functionality can provide the answer.

For advanced water metering technology to ensure revenue collection it should come with the following capabilities and functionalities as standard requirements:

- The ability to transfer payments to the water meter through a token or communication signal.
- The ability to transfer water meter readings to the municipality through a token or communication signal.

Network management

This involves monitoring, diagnosing faults and planning maintenance through collecting relevant data from pipes in the water distribution networks, with the aim of improving system performance resulting from leakage and pressure-related problems. Water balance is the way to assess the performance of the system. Having an improved water balance accuracy helps to better manage a network.

Advanced water metering technology can be used to achieve better network management in municipalities with a large difference between water abstracted and water billed. This points to water losses in the systems and installing advanced water metering technology can accurately measure abstracted water and water consumption. This measurement can be done at corresponding times to allow a more efficient water balance.

The most important requirements for system management meters are the ability to log meter readings and transmit them at regular intervals to a control point.

Understanding consumer behaviour

Advanced water metering technology can make municipalities understand consumer behaviour better when it comes to water consumption. More detailed consumption data can make water utilities understand consumption profiles and therefore take necessary proactive arrangement to sustain the water supply for the future.

Data logging and transmission capabilities are the most important requirements for meters used to understand consumer behaviour.

3.3. Evaluation framework

3.3.1. Introduction

After the technology validation process, the municipality should be in a position to identify a range of metering technology options that can serve as potential solutions for the intended objective. The project evaluation should be done before the metering technology is installed to assess its feasibility and at one point or more points after installation to assess the system's actual performance. The project evaluation is done for a particular situation to determine whether the proposed metering technology will perform adequately and to compare to the current situation and the baseline option of conventional water metering.

The approach for this evaluation framework is to estimate critical performance parameters aimed at assisting the designer to make appropriate decisions. In this process, the technologies will be evaluated on detailed technical, social, environmental and economic grounds. Indicators and variables that determine the performance on different aspects were selected and are outlined later in the chapter.

The aim of the evaluation framework is to provide a simple but effective mechanism for evaluating the viability of a proposed advanced metering project on technical, environmental, social and economic grounds. This is a complex problem and certain aspects, such as the social evaluation, are too complex to fully evaluate even with a detailed and complex framework.

It was considered critically important to keep the evaluation framework as simple as possible to make it easy to use and understand. It is not intended to be used as a black box, but as a tool to help decision-makers identify potential problems and benefits, and thus make rational decisions.

The evaluation framework’s input parameters are discussed in the next section, followed by the results in the different evaluation categories.

3.3.2. Input parameters

Each parameter of the evaluation framework is discussed in this section. Each parameter is described and the values that the parameter may adopt are discussed based on literature and a survey that was conducted on water practitioners. Typical, low and high values are determined for each parameter.

The survey referred to above was developed to obtain relevant information from water metering practitioners specifically on projects that they have been involved in. It includes sections on consumption levels, associated costs and well as meter failure rates. It was distributed at a workshop on advanced metering held in Midrand in November 2015 and further through approaching practitioners individually. Amongst the practitioners were water meter manufacturers, municipality personnel, NGOs, consultants and community liaisons. A total of 11 surveys were completed on low income schemes. The response rate to the survey was low, but the results were still considered useful in determining a typical range of values. The questionnaire used and a summary of the responses given in Appendices B and C respectively. Outcomes of the practitioners’ survey were further used in conjunction with literature to motivate for typical, low and high values of relevant input parameters.

It is worth noting that a municipality can use the framework to do their own evaluation using their own exact values. The purpose of having typical, low and high values in this chapter is to guide municipalities on values that they may not have. The range can be used to guide only in cases where the municipality does not have exact values. The sensitivity analysis in Section 3.4 indicates which parameters are significant in evaluation and hence for significant parameters it is highly recommended that actual values are obtained and used in the evaluation by the municipality.

System parameters

The system parameters describe the advanced metering project to be analysed. These are the descriptive parameters that describe the area and details of the system to be analysed. The system parameters are summarised in Table 2

Table 2: System parameters

No	Parameter	Description
1.1	Analysis ID	Unique ID for the analysis
1.2	System name	Test system
1.3	Suburb(s)	Test suburb
1.4	City	Test City
1.5	Date	Date of analysis

Global parameters

The global input parameters describe the parameters used throughout the analysis. The summary description and typical, low and high values to be expected of each input parameter are summarised in Table 3 and discussed in the rest of the section.

Table 3: Global parameters

No	Parameter	Description	Typical	Low	High
2.1	No of connections	The number of consumer connections included in this scheme	1000	200	10000
2.2	Water cost price (R/kl)	The production cost of water. Ideally this should include all raw water and water purification costs. Where a bulk supplier is used, this will be the price paid to the supplier for the water.	6.00	4.00	10.00
2.3	Applicable water tariff (R/kl) (no FBW subsidy)	The tariff used for consumption-based billing, i.e. billed metered consumption. Most municipalities use rising block tariffs and a representative water tariff should be selected from this structure.	12.00	7.50	25.00
2.3(b)	Applicable water tariff including FBS subsidy (R/kl)	Assumed first 6 kl paid from Government subsidy at R11.43/kl.	12.72	11.43	13.14
2.4	Billed unmetered tariff (R/month)	The tariff used for fixed monthly water billing, i.e. unbilled metered consumption, where this is applicable.	200	0	300

The ***number of connections*** (Item 2.1) gives the number of user connections that exists in the area where the scheme will be implemented. These include formal and informal connections directly to the system, irrespective of whether they are currently legal connections, metered or paying for the water consumed. Backyard dwellers that should obtain water from the main dwelling and not from the distribution system should be excluded.

The typical number of connections were selected as 1000 since this is the maximum number of meters that can share a vending station (GIBB, 2015). The low and high values were selected to represent what was considered to be reasonable minimum and maximum values for a single implementation. 200 would be small e.g. a pilot study. 10 000 is a substantial area and was considered large enough to show the effect of the larger scale rollout.

The ***water cost price*** (Item 2.2) is the cost the municipality incurs in the abstraction and treatment of water before it is supplied to the system. For municipalities that use their own treatment and abstraction facilities, this will be the cost of production. For municipalities that use a bulk water supplier, this is the purchase price of the bulk water. This value excludes distribution system costs such as operation, maintenance, metering, meter reading and billing costs.

According to Eberhard (2003) individual water charges vary widely across South Africa due to the large number of links in the water supply chain that are regulated in different ways and by different entities. The graph below shows the different water cost prices in different regions and municipalities in South Africa. Figure 9 shows cost prices in 2003.

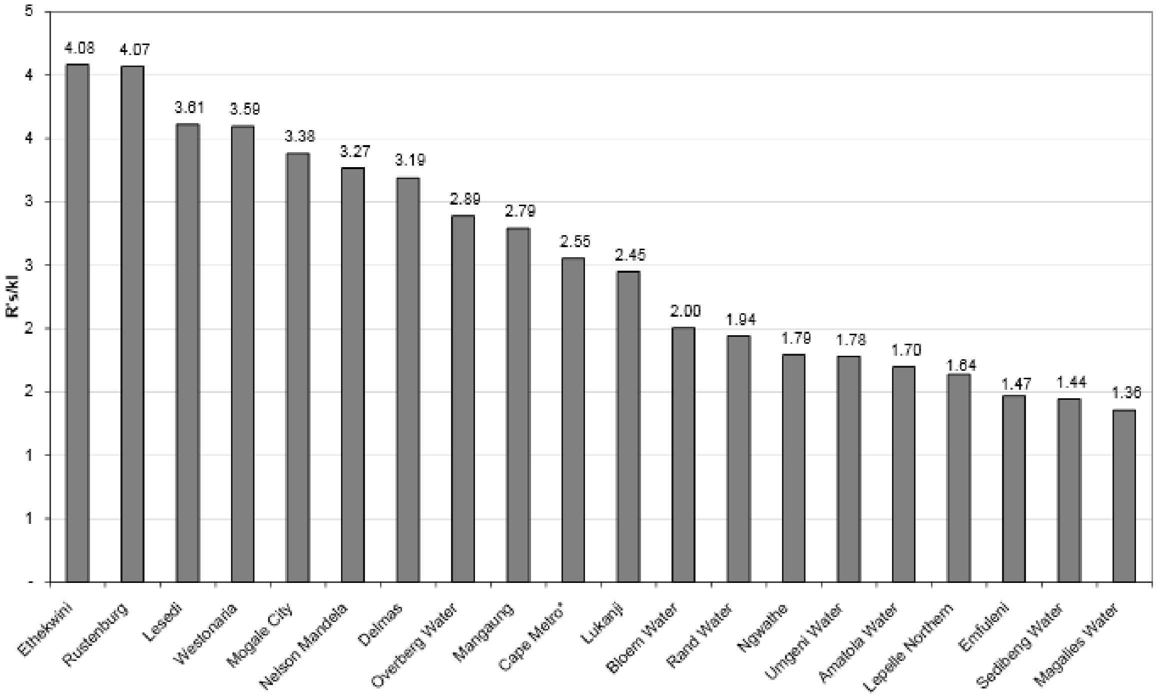

Figure 9: Bulk water Prices in 2003 (Eberhard, 2003)

The cost prices were adjusted for inflation to 2016 values using inflation calculator for South Africa showing them to vary between R2.65 to R7.96 (Crause; 2016).

However, Eberhard (2003) found the annual nominal increases in bulk water tariffs to be significantly higher than inflation between 1997 and 2001. Thus the values above are likely to underestimate the true current price.

In the practitioner survey four correspondents reported prices between R 6 /kl and R 10 /kl, which corresponds reasonably well with the inflation-adjusted values from Eberhard (2003). From a recently conducted feasibility study on prepaid meters in eThekwini, it was highlighted that the eThekwini Water and Sanitation purchases water from Umgeni Water at R 4.95 per kilolitre as of 2015 (GIBB, 2015).

Based on the above, a typical bulk water price of R7 was selected, and low and high values of R3.00 and R10 to give a wide enough range.

The ***applicable water tariff*** (Item 2.3) is the average price that the consumer pays to the municipality for water consumed. Since municipalities can use different tariff structures and rising block rates, this value should be the weighted average price paid by consumers in the study.

According to a study on average water demand by suburb (Griffioen & van Zyl 2014) the daily demand for properties is a function of stand size, but also of a large number of other factors such as income and climate. For smaller property size range that is typical in low income urban areas, unit consumption varied between 6 and 30 kl/month. Since this number also includes high density high income areas, more emphasis was placed on the lower consumption data points.

In low-income areas the average consumption is often found to be substantially higher due to a lack of maintenance and high on-site leakage rates. However, since these high consumption rates are invariably associated with non-payment for the service, they were not considered when estimating the tariff range paid.

Based on the above, typical, low and high values of 12, 6 and 22 kl/day were assumed for low income areas where consumers pay for the water used. These values were then used to estimate the typical water tariff. Table 4 shows the block tariffs for Johannesburg and Cape Town metro municipalities as in the year 2014/2015. The price for water consumed for 6, 12 and 22 kl/month were calculated based on the average rate in each block in Table 4 and was found to be zero, R4.20 /kl and R8.85 /kl.

As indicated by Muller (2008), the municipalities have to set the tariffs in a way that high volume users cross subsidise the FBW allocation. However, with municipalities that are too poor to achieve that, the constitution provides for an inter-governmental transfer, the "equitable share of revenue" from the national level. On the one hand, findings of the feasibility study in eThekwini indicate that value of the FBW allowance as provided by the National Treasury as R 11.43. Assuming first 6 kl subsidised at R11.43/kl the tariffs for 6, 12 and 22 kl now become R11.43, R12.72 and 13.14 /kl respectively

Table 4: eThekwini, Johannesburg and Cape Town tariffs (City of Cape Town, 2016; eThekwini municipality (2016); City of Johannesburg (2016))

Step (KL)	Cape Town (R/KL)	eThekwini (R/KL)	Johannesburg (R/KL)
1-6	0	0	0
6-9	8.75	0	6.18
10-15	12.54	12.79	9.97
16-20	18.58	12.79	14.06
21-25	18.58	12.79	18.46
26-30	18.58	17.04	18.46
31-35	18.58	26.28	19.67
36-40	22.94	26.28	19.67
41-45	22.94	26.28	24.24
46-50	22.94	28.91	24.24
51 and above	30.27	28.91	24.24

In the practitioner survey it was found that the applicable water tariff ranges from R 7.50 /kl to R 25 /kl by 5 respondents. The highest value is unlikely and probably refer to the top block tariff and not the average tariff, but the lower value tie in well with the estimate above.

The ***Billed unmetered tariff*** (Item 2.4) is the flat rate tariff charged to consumers who are not billed based on metered consumption. This is normally a monthly figure that the municipality charges its consumers based of parameters such as stand size or land use type and consumer category.

The city of Johannesburg charges a flat water rate of R 192.19 /property for indigent consumers (City of Johannesburg, 2014). Marah et al (2004) found that prior to installation prepaid meters a flat rate of R 50 per month was charged in 2004, which is R97.43 in 2016 terms.

Based on the above, a typical *billed unmetered tariff* of R 200 /month was selected, and low and high values of zero and R300.

Current situation parameters

This section deals with the system before any intervention is implemented. It is discussed in three sections; current consumption; current payment rate and other parameters.

Current Consumption

The current consumption is entered in three categories, i.e. *billed metered*, *billed unmetered,* and *illegal or unbilled consumption*. A summary description of the required input parameters, typical value, low and a high value are given in Table 5. The input parameters are discussed in more detail in the rest of this section.

Table 5: Current situation consumption parameters

No	Parameter	Description	Typical	Low	High
3.1	Number of connections billed on metered consumption	Billed metered consumption includes all properties that are metered and billed based on their actual consumption.	500 (50%)	0 (0%)	1000 (100%)
	Unit cost of billed metered connections (KL/property/month)	The average monthly consumption (in kL/month) of properties billed on metered consumption	9	6	40
3.2	Number of connection billed unmetered consumption	Billed unmetered consumption includes all properties that are not metered but are billed for water consumption, or are metered but not billed based on their actual consumption. Billed unmetered properties will normally be billed a flat rate for their water consumption.	150 (15%)	0 (0%)	300 (30%)
	Unit cost of billed unmetered consumption (KL/property/month)	The average monthly consumption (in kL/month) for billed unmetered consumption.	30	0	60
3.3	Illegal or unbilled connections (KL/property/month)	Illegal connections include all properties that have illegal or unregistered connections to the water distribution system. The number of illegal connections is the total number of properties minus the numbers of billed metered and billed unmetered properties. The number of properties and their average monthly consumption (in kL/month) are required in the model.	30	0	60

		The total monthly consumption for this category is calculated in the table.			
3.4	Total/ average	The total number of properties included in the analysis is calculated as the sum of the billed metered, billed unmetered and illegal connections. The number of properties has to equal the number of properties (entered under global input parameters).	-	-	-

The category ***billed metered consumption*** (Item 3.1) includes all connections that are billed based on their actual consumption, irrespective of whether they pay for the water or not. ***Billed unmetered consumption*** (Item 3.2) includes all connections that pay a flat rate for their water and ***illegal or unbilled consumption*** includes formal connections that are currently not billed and illegal connections that should be converted to formal connections.

The sum of the connections of the three categories should add up to the number of properties (Item 2.1).

The ***number of connections*** in each category can be estimated as a fraction of the total number of connections for the different scenarios. Since this varies greatly between different supply areas, the distributions in Table 6 were assumed.

Table 6: Fraction of properties billed metered, billed unmetered and illegal connections

Scenario	Fraction of properties		
	Typical	Low	High
Billed metered consumption	50	30	80
Billed unmetered consumption	30	30	20
Illegal consumption	20	40	0

The ***unit consumptions*** were estimated from published values and the practitioner survey.

Billed metered consumption range for systems in a reasonably good condition and where consumers pay for their consumption was discussed later in this section , and typical, low and high values of 9 kl, 6 kl and 40 respectively were used. However, systems where advanced meters are implemented are unlikely to have the levels of payment and service assumed to obtain these values.

Low income areas often have very high on-site leakage rates, resulting in increased consumption values. For instance, on a study on onsite leakage in Johannesburg it was found that overall 64 % of investigated properties had measurable on-site leakage at an average rate of 22.9 I/h per property, equivalent to a monthly volume loss of 16.5 kl per property representing 25% of the overall consumption (Lugoma, et al., 2012). Couvelis & van Zyl (2012) in the study on on-site leakage found that 16% and 28% of properties in Cape Town and Bloemfontein have measurable on-site leakage significantly contributing to the water consumption. The average leakages are 15 kl/month and 28 kl/month in Cape Town and Bloemfontein respectively. In cases where the on-site leakage is so high, an advanced metering project will not be able to succeed without addressing the on-site leakage by fixing and retrofitting plumbing systems.

In a study on prepaid meters by Marah et al (2004), in Nkomazi the average unit consumption was 40 kl per household per month before implementation of prepaid meters and 7 kl per household per month after installation (Marah, et al., 2004). The results of the practitioners' survey indicate the value to range from 3 kl/property/month to 15 kl per month. The range is reasonably considered to range from 6 kl/property/month (FBW) to 40 kl/property/month and the typical *unit consumption for the billed metered connection* is selected to be 9 kl/property/month.

The results of the practitioners' survey indicate that the unit consumption of the billed unmetered connections ranges from 0 kl/property/month to 60 kl/property/month from 3 respondents. According to the feasibility study on prepaid meters in eThekwini, it was established that consumption is reduced from 1 kl per day (30 kl per month) to 0.5 kl per day (15 kl per month) after installing water meters (GIBB, 2015) meaning an unmetered consumption of 30 kl/property/month. While in Phiri, the water consumption is claimed to be 66.7 kl/property/month prior to installation of prepaid meters, that is in areas where consumers we charged a flat rate tariff (Singh & Xaba, 2006). The results of the practitioners' survey indicate that the average monthly consumption for properties billed a fixed rate for water as 30 kl from one respondent. Thus the typical, low and high values are selected to be 30 kl, 6kl and 60 kl respectively.

The study on feasibility of prepaid metering system in eThekwini, the extent of illegal connections was found to range between 0% and 52% (of the connections); which translates to 0 to 520 (GIBB, 2015). The 70% upper limit is quite high and it is worth noting the figure was so high in eThekwini in areas where water restrictors were installed due to consumer failure to pay for their consumption. The results of the practitioners' survey indicate that the fraction ranges from 0 to 70% from 6 respondents. The typica*l number of the illegal or unbilled connections* is selected as 100 (10% of the total properties).

The typical *unit consumption for the illegal or unbilled connections* as 30 kl/property/month because it was not known by practitioners but since these connections are not billed based on actual consumption tis figure can be thought to be in the same range as the *unit consumption for billed unmetered connections*.

The *Total* number of properties is calculated as the sum of the billed metered, billed unmetered and illegal connections. The number of properties has to be equal to the number of properties in the scheme.

Table 7 shows the average billed metered, unmetered and illegal consumption levels for the typical, low and high systems.

Table 7: Billed metered, unmetered and illegal consumption

	Typical	Low	High
Billed metered	20	6	40
Unmetered	30	15	50
illegal	40	20	60

Current situation parameters: payment level

The current situation input parameters comprise of data related to the current situation in the study area. This section covers the parameters and variables related to payment level. A summary description of the required input parameters, typical value, low and a high value are given in Table 8. The input parameters are discussed in more detail in later sections to provide guidance on selecting appropriate values.

Table 8: Current situation parameters: payment level

No	Parameter	Description	Typical	Low	High
3.5	Billed metered consumption (%)	Fraction of billed metered properties currently paying their full water bill.	50	10	90
3.6	Billed unmetered consumption (%)	Fraction of billed unmetered properties currently paying their full water bill.	40	0	75
3.7	Total/average	The total number and fraction of paying properties are calculated, as well as the total income from water sales in the study area. These values be checked against historic treasury data if possible.	-	-	

The current situation regarding ***payment levels*** of ***Billed metered consumption*** (Item 3.5) reflects on payment levels in low income areas where conventional meters are used. The experience with prepaid meters is discussed under later in this chapter.

A study in eThekwini (GIBB, 2015) showed that only about 10 of low income residents with conventional metering had their account in arrears. The eThekwini municipality is strict with non-payment for water; and annual 12% interest is charged on arrears and flow restrictors are installed on consumers' points where the account has been unpaid for 60 days (GIBB, 2015). According to the same study, approximately 20% of the connections have been disconnected due to non-payment in low income areas of eThekwini.

A study by Marah et al (2004) indicates that before prepaid meters were installed in Umzimvubu Municipality, the collection levels were approximately 30 % and the results of the practitioners' survey indicate that the fraction ranges from 0% to 50% from 2 respondents. The typical fraction of the billed metered consumption that is paid in full is selected as 50%, with a high level of 90% based on eThekwini and a low value of 10%

The current situation regarding ***payment levels*** of ***Billed unmetered consumption*** (Item 3.6) reflects payment levels in low income areas where fixed water charges are used.

The study on cost recovery by Marah et al (2004) found that the Letsemeng Municipality experienced a very low rate of payment for fixed-rate and unmetered water services of 1% (Marah, et al., 2004). The results of the practitioners' survey indicate that fraction of 100% from 1 respondent. With little information on payment rates for fixed charges available, but a sense that this will be lower than for metered connections, values of 40, 0, and 75% were selected for the typical, low and high values respectively.

Other current parameters

The current situation input parameters comprise of data related to the current situation in the study area. This section covers the social parameters that are prevailing in low income communities that may affect the public acceptance of the metering system to be installed. A summary description of the required input parameters, typical value, low and a high value are given in Table 9. The input parameters are discussed in more detail in later sections to provide guidance on selecting appropriate values.

Table 9: Other current parameters

No	Parameter	Description	Typical	Low	High
3.9	Fraction of demand that is on-site leakage (%)	The fraction of the estimated demand that is made up of on-site leakage.	40	5	70
3.10	Ave time between meter readings (months)	How frequently water meters are currently read.	2	1	3
3.11	Meter reading cost (R/meter/month)	The cost of taking a water meter reading, including transport, labour and equipment.	2.50	1.50	3.00
3.12	Billing cost (/bill)	The cost of entering the meter reading data into the billing system, generating, printing and mailing a water bill.	10	5	15

3.14	Meter operation & maintenance cost (/meter/month)	The cost of operating and maintaining the water meter.	3.00	1.00	5.00
Fraction of meters failing due to:					
3.15	Meter failure (/year)	The fraction of existing meters that need replacement due to failure of the meter itself.	5	3	10
3.16	Vandalism and other (/year)	The fraction of existing meters that need replacement due to vandalism to the meter.	3	1	7
3.18	Total (/year)	The total fraction of meters that need to be replaced per year due to failure or vandalism	-	-	-
3.19	Average household income (/month)	The average household income of properties in the study area.	3000	1500	10000
3.20	Unemployment rate	The average unemployment rate in the study area.	50	30	70

3.21	Volatility of community (No of protest or mass action incidences per year)	The average number of incidences of protest or mass action occurring in the study area per year.	3	1	5

The ***fraction of demand that is on-site leakage*** (Item 3.8) is the fraction of estimated demand that is made up of on-site leakage. On-site leakage is the leakage that occurs on consumers' property, i.e. on the consumer side of the water meter. This includes leaks from elements such as pipe fittings, taps, toilet cisterns and other household appliances (Lugoma, et al., 2012).

In the study on extend of on-site leakage on selected medium and high income suburbs of Johannesburg, it was found that 64% of residential properties had measurable on-site leakage with an average flow rate of 12 kl/month (Lugoma, et al., 2012). In the same study it was found that the average on-site leakage can be reduced by almost two thirds by fixing leaks in the 10% of the properties with most leakage.

In the study on extend of onsite leakage in selected suburbs of Cape Town it was found that 16.4% of 402 properties investigated in the City of Cape Town had an on-site leakage and their median flowrate was 10 litres/ hour translating to 7.2 kl/month/property (Couvelis & van Zyl, 2012). However, according to the same study, in the low income areas of Cape Town the percentage of properties with on-site leakage ranged from 17% in Mandela Park in Khayelitsha to 42% in Langa with mean flowrate translating to approximately 47 kl/month/property while in the low income areas of Mangaung the percentage of properties with on-site leakage ranged from 3% in Motlatla to 62% in Freedom Square; translating to approximately 30 kl/property/month. The low percentage for Motlatla is possibly due to the level of service provided; full house connection was not provided but only a tap was provided. On the one hand, as cited by Couvelis & van Zyl (2012), Frame et al (2009) indicated that 62% of 8 000 low income properties of Cape Town had on-site leakage prior to a water leakage repair program and through the program, consumption was reduced from 19 kl/month/property to 11.5 kl/month/property. This translates to a percentage of 40%. On the other hand, the results of the practitioners' survey indicate that in low income communities the fraction of demand that is on-site leakage ranges from 5% to 70% from 4 respondents. Thus the typical, low and high values are selected to be 40%, 5% and 70% respectively.

The ***average time between meter readings*** (Item 3.9) is the frequency at which water meters are currently being read. Ideally these should be once a month and not less that once every 3 months.

Heymans, et al., (2014) in the study on ‘Limits and Possibilities of Prepaid water in urban Africa’ indicates that it is advisable that it is important that the montlhy manual meter reading is carried out as a way to inspect the possibilities of illegal connects (Heymans, et al., 2014). Also in the practitioners’ survey the average time between meter readings ranges from montlhy to quaterly from 4 respondents. Following the importance of manual meter reading the typical, low and high values of 2, 1 and 3 are selected respectively.

The ***meter reading cost*** (Item 3.10) is the cost of taking a manual water meter reading, including transport, labour and equipment.

The results of the practitioners’ survey indicate that the cost of manual meter reading ranges from R 4.00 to an unreasonable sounding R 100.00. In the Economic feasibility of advanced metering technology in Melbourne it was established that the cost of meter reading is 60 Australian cents per meter per reading (Blom, et al., 2010), which is equivalent to R 4.40 in South African currency in 2010... A study in eThekwini the established to range from R 1.74 to R 4.00 . The results indicate that the R 1.74 is the cost of reading a meter in informal settlements while the R 4.00 is the cost of reading a meter in rural areas as the properties are clustered together in informal settlements and remotely located leading to increased traveling expenses. The typical meter reading cost of R4.00 is selected and the range is selected to be from R 2.00 and R 8.00 per meter per month (GIBB, 2015).

The ***billing cost*** (Item 3.11) is the cost of entering the meter reading data into the billing system, generating, printing and mailing a water bill to the consumer.

The practitioners’ survey, the respondents could not estimate the billing cost while from the feasibility study on prepaid meters in eThekwini the cost was assumed to be R10 per month per meter with the cost breakdown as shown below (GIBB, 2015):

- R 6 administrative cost
- R 1 printing cost
- R 3 postage cost

Looking at the cost breakdown, the typical cost of billing is selected as R 10 with the range between R 5 to R15.

The ***meter operation & maintenance cost*** (Item 3.12) is the cost of operating and maintaining the water meter. This cost is dictated by maintenance requirement of a water meter; that is through specified maintenance intervals of a meter and a strainer.

The results of the practitioners' survey indicate that the meter operation & maintenance cost ranges from R 0 to R 100/year (R 8.33/month) from 3 respondents. However, the R 0 is possibly in a situation in which no maintenance is being made on meters while R 8.33 seems too high for conventional meters but possibly refers to a situation where prepaid meters were installed as the figure is from the scheme based in Johannesburg. On the one hand, according to SGS Economics and Planning, (2011) the annual maintenance cost of the meter is expected to be 15% of the total purchase cost. Taking the cost price of R 200.00 the typical meter operation & maintenance cost of R 2.50 per month per meter. Thus the typical, low and high values of R 3.00, R 1.00 and R 5.00 are selected.

The ***meter failure*** (Item 3.13) is the fraction of existing meters that needs replacement due to failure of the meter itself. This number should reflect the ideal situation where meters that fail are replaced immediately. Thus even if all failed meters are not currently replaced, the value should reflect the ideal fraction of replacements rather than the actual one.

Couvelis & van Zyl (2015) on the study on apparent losses investigated the meters installed in eThekwini in the period; 6th June 2005 to 28 March 2010 (5 years). As part of the observations of the study it was observed that in that period approximately 19 % of the meters were replaced more than once in that period. This figure translates to a fraction of approximately 4 % per year. The fact that the meters were replaced more than once in that period of 5 years eliminates the possibility of the meters to have been replaced due to old age, leaving the possibility of meter failure and vandalism as reasons for replacement. That implies that 4% of the meters failed due to either meter failure of vandalism. However, due to strict policy of eThekwini municipality that if a consumer is found to have tampered with the meter more than 3 times, the water connection will be removed leads to an assumption that this meters are replaced due to the meter failing itself. On the one hand, the study in eThekwini it was cited that from 1 July 2013 to 30 June 2014 (1 year) 8.8 % of conventional meters in the database were changed out (GIBB, 2015). On the other, results of the practitioners' survey indicate that the fraction of meters failing due to the meter failure ranges from 5 % to 50%. However, the 50 % failure rate was in Johannesburg and Mangaung where prepaid meters were also installed and that might be unlikely to be failure rate of conventional meters only. The typical, low and a high fractions of 5 %, 3 % and 7%.

The ***fraction of meters failing due to vandalism*** (3.14) and other is the fraction of existing meters that needs replacement due to vandalism to the meter. This number should reflect the ideal situation where meters that fail due to vandalism are replaced immediately. Thus even if all vandalized meters are not currently replaced, the value should reflect the ideal fraction of replacements rather than the actual one.

The results of the practitioners' survey indicate that the fraction of conventional meters failing due to vandalism ranges from 30 % to 40 % from 4 respondents; but these fractions seem to be unrealistically high and might have not been strictly referring to conventional but prepaid meters. Due to municipalities implementing stricter policies of how to deal with consumers found to have bypassed the meters, the fractions are expected to be slightly lower than that of meters failing due to the meter failing itself. Thus the typical, low and high values of 3 %, 1 % and 7% respectively.

The ***average household income*** (Item 3.16) is the average monthly income of properties in the study area. This value may be obtained from Census data or other income studies.

According to statistics, the median household income was found to be R 2 800 per month (Statistics South Africa, 2010). The net present value of this figure is R 3 600 per month. However, in low income areas, this figure can be expected to be slightly less than that. On the one hand the results of the practitioners' survey indicate that the figure ranges from R 1 500 to R 10 000. The typical, low and high values for the average household income of R 3 000, R 1 500 and R 10 000.

The ***unemployment rate*** (item 3.17) is the average number of people without formal employment and the figure can be obtained from Census data or other employment studies of the area of study.

Muller (2008) indicates that a large portion of low income residents has low education level and skills and hence low employability. The general unemployment level of 40 is prevailing in low income areas of South Africa. The results of the practitioners' survey indicate that the unemployment rate ranges from 30% to 70%. 50%, 30% and 70% is selected as typical, low and high value for unemployment rate in low income areas of South Africa.

The ***volatility of community*** (Item 3.18) (No of protest or mass action incidences per year) is the average number of incidences of protest or mass action occurring in the study area per year.

The results of the practitioners' survey indicate that the average number of mass action incidences per year ranges from 1 to 5. Thus the typical, low and high values of 3, 1, and 5 are selected respectively.

Proposed system parameters: system parameters

The proposed scheme input parameters comprise of data related to the proposed advanced metering installation. The option of using conventional water meters in the scheme is to be provided as a baseline for evaluating the benefits of the advanced metering system. This is important since advanced metering schemes are considerably more complex and costly than conventional metering. The complexity, electronics and additional components such as communication and billing systems of advanced metering makes a higher failure rate and increases operation and maintenance costs inevitable. This means that advanced metering schemes will not be suitable in all situations. The purpose of this evaluation system is to assist the designer with making rational decisions on whether a specific advanced metering scheme is appropriate for a given situation or resorting to conventional meters is a good idea.

The key technical parameters for the evaluation of conventional and prepaid metering technology are presented in Table 10, and the parameters are discussed in more detail in the later sections to provide guidance on selecting appropriate values

Table 10: Proposed system parameters

No	Parameter	Description	Prepaid			Conventional		
			Typical	Low	High	Typical	Low	High
4.8	Mean battery life (years)	The mean battery life of the advanced water meters	6	3	9	-	-	-
4.10	Effective meter service life (years)	Expected service life of the water meter, including all components except for the battery.	10	6	15	15	10	20
4.12	Water meter failure (%)	The expected fraction of meters that will need replacement annually due to failure of the meter itself.	10	5	15	5	3	10

4.13	Electronics and other components (e.g. valve) failure	The expected fraction of meters that will need replacement annually due to failure of the electronic components of the meter.	10	5	35	-	-	-
4.14	Vandalism	The expected fraction of meters that will need replacement annually due to damage caused by vandalism.	7	5	10	3	1	7
4.16	Total	The total fraction of meters that needs to be replaced per year due to all possible causes.	-	-	-			

The ***meter make*** (Item 4.1) is the type of meter to be installed in the proposed scheme and it is entirely a manufacturer. This should also indicate the name of the manufacturer and the type of meter and has to state what type of metering it is.

The typical meter make in low income community schemes is conventional meters and prepaid meters from local manufacturers across the South Africa.

The ***meter model*** (Item 4.2) is the type of meter to be installed in the proposed scheme. The meter model is basically based on the measuring mechanism used by the meter.

The typical *meter model* of positive displacement is selected as most municipalities use this meter model.

The ***SANS 1529-1 compliance*** (Item 4.3) is the checking of whether the mechanical meter part conforms to the national standards for mechanical water meters for potable water.

The typical state of meters installed in South Africa is that they are compliant (TRUE) since this is the legislative requirement.

The ***SANS 1529-9 compliance*** (Item 4.4) is the checking of whether the electronic components of the metering system conforms to the national standards for electronic components of water meters.

The typical state of prepaid meters installed in South Africa is that they are compliant (TRUE).

The ***Mean battery life*** (Item 4.5) is the average time number of years a battery lasts. This is not applicable to conventional meters since they do not have batteries.

The expected battery service life is normally specified by manufacturers. The meter manufacturers claim a battery life exceeding 10 years. However, this is subject to variation as the test conditions tend to differ from operating conditions. The meter might be subject to different, temperature, pressure, humility hence the actual battery life can significantly vary across the installed meters. Studies, indicate that battery life can be as short as 1 year and as high as 10 years (Heymans et al., 2014). On the one hand, results of the practitioners' survey indicate that the mean battery life ranged from 2 to 10 years from three respondents. Thus the typical, low and high values for the mean battery life are selected as 6, 3, and 9 years respectively.

The ***Battery being replaceable in field*** (Item 4.6) is the indication of the amount of time required before the battery is replaced after the battery has been indicated or reported to have run flat.

The typical battery for prepaid meters is selected to be replaceable in the field since the results of the practitioner study indicate that all prepaid meters have batteries that are replaceable in the field therefore the 'TRUE' option is a typical state of battery replicability in the field.

The ***Meter service life*** (Item 4.7) is the expected service life of the water meter, including all components except for the battery. This is the expected lifespan of a meter is the duration of which the meter is expected to be in operation. The expected battery service life is normally specified by manufacturers. However, this is subject to variation as the test conditions tend to differ from operating conditions. The meter might be subject to different, temperature, pressure, humility and electromagnetic interferences.

The results of the practitioners' survey indicate that the meter service life of conventional and prepaid meters range from 5 to 25 years and 5 years to 15 years respectively; from 6 respondents. On the one hand, Heymans et al (2014) on the study on 'Limits and Possibilities of Prepaid meters in urban Africa' indicate that conventional meters can be in operation for up to 30 years while prepaid meters can be in operation up to 20 years but are only effective for 10 and 7 years respectively. The typical service life of 15 years is selected for conventional meter and a typical service life of 6 is selected for prepaid meters and the ranges are selected as from 10 to 20 years and from 6 years to 15 years for conventional and prepaid meters respectively.

For the ***Effective service life*** (Item 4.8) if a meter uses a battery that cannot be replaced in the field, the effective service life is determined as the shortest of the meter and battery service lives. If the meter doesn't use a battery, or has a battery that can be replaced in the field, the effective service life is set to the meter service life.

The typical effective service lives of 10 and 15 years are selected for conventional and prepaid meters respectively because the prepaid meters are replaceable and conventional meters do not use batteries.

The ***fraction of meters expected to fail due to water meter failure*** (Item 4.9) is the fraction of meters that will need replacement annually due to failure of the meter itself.

The expected fraction of meters to fail due to water meter failure for conventional meters is as stated in item 3.13; the typical, low and a high fractions of 5 %, 3 % and 10%.

The fraction of prepaid meters failing due to the meter failing itself can be expected to be similar to that of conventional meters only if the prepaid meter is a separate conventional meter and additional components and can be expected to be slightly higher for integrated prepaid meter. The results of the practitioner survey indicate that the fraction of prepaid meters failing due to the meter failure itself ranges from 1 % to 60 % from 7 respondents. On the one hand the study on cost recovery by Marah et al (2004) indicate that prepaid meters' failure rate can go as high as 40 % per annum (meter and electronics inclusive). However, since prepaid meters comprise of a mechanical meter and additional components, one cannot expect this fraction to significantly vary from expected failure rate conventional meters failing due to the water meter failing itself. Thus a slightly higher figures are to be expected. Hence the typical, low and high values are selected as 10 %, 5 % and 15 % respectively.

The ***fraction of meters expected to fail dues to Electronics and other components failure*** (Item 4.10) is the expected fraction of meters that will need replacement annually due to failure of the electronic components of the meter. Conventional meters do not have this components of meter failure

As mentioned in Item 4.9 above, a study by Marah et al (2004) indicate that fraction of prepaid meters expected to fail can go as high as 40% (meter, vandalism, and electronics). On the one hand, the results of the practitioners' survey indicate that the fraction of prepaid meters failing due to electronics and other components range from 1 % to 70 % from 6 respondents. On the other hand, Heymans, et al (2014) brings forward that in a performance audit of prepaid meters in Mogale; 8 yeas after installation a total 90 % of the meters were faulty due water meter failure, vandalism, electronics and other components. This value translates to about 12 % meaning that the fraction failing due to electronics and other components will slighlty be less than this 12 %. Thus the typical, low and high values for this item are selected to be 10 %, 5 %, 35 %. However, this depend on the manufacturers and the make of the prepaid meter.

The ***expected fraction of meters to fail due to vandalism*** (Item 4.11) is the expected fraction of meters that will need replacement annually due to damage caused by vandalism.

As stated in item 3.14, the typical, low and high values of 3 %, 1 % and 7% respectively are to be expected as fraction of meters failing due to vandalism for conventional meters.

As cited in the feasibility on prepaid meters in eThekwini the fraction of prepaid meters failing due to vandalism in Johannesburg is 30% while it is estimated to be 7.5% in eThekwini (GIBB, 2015). The reason for a high value in Johannesburg is possibly because of high activism in the areas where vandalism happens. However, this values are expected to be slightly higher than that of conventional meters due to self-disconnection functionality of the prepaid meters. Hence, typical, low and high values of 7 %, 5 % and 10 % are selected.

Proposed system parameters: cost

The proposed scheme input parameters comprise of information on costs related to the proposed advanced metering installation as well as conventional metering installation. This is information is useful in determining the financial viability of the proposed metering solution comparing it to the financial viability of conventional metering.

The key technical parameters for the evaluation of conventional metering and prepaid metering technology are presented in Table 11; and the parameters are discussed in more detail in the later sections to provide guidance on selecting appropriate value.

Table 11: Proposed scheme parameters: cost

No	Parameter	Description	Prepaid			Conventional		
			Typical	Low	High	Typical	Low	High
4.17	Meter price (R/meter)	The price of the meter only.	1500	1000	2000	200	150	250
4.18	Installation cost (R/meter)	The cost of installing the meter.	300	250	500	200	150	400
4.19	Communication infrastructure cost (R)	The total cost of communication infrastructure if included in the advanced metering installation	120 000	80 000	160 000	-	-	-

4.20	Payment infrastructure cost (R)	The total cost of payment infrastructure, including vending terminals, billing software, computer hardware and additional staff that will be required.	80 000	40 000	120 000	-	-	-
4.21	Battery replacement cost (R/meter)	The cost of replacing a battery in the advanced meters, including the cost of the new battery, disposal cost of the old battery and labour.	300	200	350	-	-	-
4.22	Meter reading cost (R/meter)	The cost of reading the meter. The costs should include all related costs, such as transport, labour and equipment.	3	1	5	3	1	5
4.23	Meter operation & maintenance cost (/meter/month)	The cost of operating and maintaining water meters.	20	15	30	2.50	1.25	5.00

4.24	Billing cost (R/bill)	The cost of entering the meter reading data into the billing system, generating, printing and mailing a water bill	-	-	-	10	5	15

The ***Meter price*** (Item 4.14) is the cost of purchasing a water meter. This is the actual price that the municipality pays for the water meter with discount inclusive.

According to the study on feasibility of prepaid meters in eThekwini, the conventional water meter price alone is R 150.00 (GIBB, 2015) while the price of prepaid meters range from R 850.00 to R 2 600.00 from three local manufactures. On the one hand, the results of the practitioner survey indicate that a price for conventional meters range from R 250.00 to R 1 500.00. The R 1 500.00 is unreasonably high and is probably for a prepaid. Hence the typical, low and high values for the conventional meter are selected to be R 200.00, R 150. 00 and R 250 while for prepaid meters typical, low and high values are selected to be R 1 500.00, R 1 000.00 and R 2 000

The ***installation cost*** (Item 4.15) is the cost of installing the water meter. This includes costs such as labour cost.

The typical installation cost of R300 is selected for both conventional and prepaid meters since the results of the practitioners' survey and findings of the EThekwini feasibility on prepaid water meters indicate that the price ranges from R170 to R400. Thus the typical, low and high values are selected to be R 300.00, R 250.00 and R 500.00 for prepaid meters while for conventional meters are expected to be slightly lower than that of conventional meters as prepaid meters need to be set up as opposed to conventional meter. The typical, low and high values for conventional meters are selected to be R 200.00, R 150.00 and R 400.00.

The ***Communication infrastructure cost*** (Item 4.16) is the total cost of communication infrastructure required for the metering system.

From the feasibility study of prepaid meters in EThekwini it was established that the annual cost of communication infrastructure is R120 000 (GIBB, 2015) while from the practitioners' survey, none of the practitioners could estimate the cost of communication infrastructure. This cost in only applicable to prepaid meters and not applicable to conventional meters. The typical cost of R120 000 is selected and the range selected to be from R80 000 to R160 000.

The ***Payment infrastructure cost*** (Item 4.17) is the total cost of payment infrastructure, including vending terminals, billing software, computer hardware and additional staff that will be required.

From the practitioners' survey, none of the practitioners' could estimate the cost for payment infrastructure. However, in the feasibility study on prepaid meters in EThekwini this cost was estimated to be R120 000 for prepaid meters. The R120 000 is then selected as the typical cost for payment infrastructure required for prepaid meters while it is considered inapplicable to conventional meters and it is rather incorporated in the billing cost. The range can be estimated to range from R40 000 to R120 000 for prepaid meters.

The ***Battery replacement cost*** (Item 4.18) is cost of replacing a battery in advanced water meters (prepaid meters), including the cost of the new battery, disposal cost of the old battery and labour.

The typical cost of the battery replacement cost of R300 is selected since the results of the practitioners' survey indicate the cost to range from R 200 to R350. Thus the typical, low and high values are selected to be R 300, R 200, and R 350 respectively.

The ***Meter reading cost*** (Item 4.19) is the cost of reading a meter. The cost includes all related costs, such as transport and labour and equipment.

According to the EThekwini feasibility study on prepaid meters, manual meter reading currently costs the Municipality R 1.74 per meter per month and R 3 per meter per month in low-cost housing projects and rural areas respectively. The increased cost is due to rural consumers being more remotely located and the subsequent increased travel expense (R. Maharaj, 2015). The typical, low and high values for meter reading cost are selected to be R 3.00, R 1.00 and R 5.00. These values are assumed to be applicable to conventional metering and not prepaid meters. However, the same values can be used but it should be noted that with prepaid meters meter reading is not done for billing purposes and can be done once a year just as a routine inspection for illegal connections and checking the accuracy of the sales collection.

The ***Meter operation & maintenance cost*** (Item 4.20) is the cost of operating and maintaining water meters after installation. This cost is dictated by maintenance requirements of a water meter; that is through specified maintenance intervals of a meter and a strainer.

For conventional meters, the typical, low and high values are R 2.50, R 1.25 and R 5.00 as indicated in Item 3.12. As mentioned earlier in item 3.12, according to SGS Economics and Planning, (2011), the annual maintenance cost of a water meter is expected to be 15% of the purchase cost. Taking the cost price of R 1 500.00 for prepaid meters, the typical operation and maintenance cost of R 18.75 is to be expected. Following that, the typical, low and high values of R 20.00, R 15.00 and R 30.00 are selected respectively.

The ***Billing cost*** (Item 4.21) is the cost of entering the meter reading data into the billing system, generating, printing and mailing a water bill if conventional and advanced meters are installed respectively.

This cost was assumed to be R10 per meter per month in the EThekwini prepaid metering system (GIBB, 2015). This is component of the operations cost is said to be applicable to all metering technology that involves delivery of a bill to the consumer, therefore prepaid systems carry a zero cost for this component.

From the very same study it can be inferred that the cost break down for sending a bill is as follows:

- R 6 administrative cost
- R 1 printing cost
- R 3 postage cost

Based on the above breakdown, an estimation can be made for the overall cost to send a bill for the municipality. The typical cost of R10 is selected while the range is established to be from R5 to R15.

Proposed system parameters: expected new consumption

The proposed scheme input parameters comprise of data related to the expected situation in the study area if either and option of conventional or prepaid meters is implemented. A summary description of the required input parameters, typical value, low and a high value are given in Table 12. The input parameters are discussed in more detail in later sections to provide guidance on selecting appropriate values.

Table 12: Proposed system expected consumption level

No	Parameter	Description	Prepaid			Conventional		
			Typical	Low	High	Typical	Low	High
4.28	Billed metered consumption (kL/property/month)	The estimated average monthly consumption for properties billed on actual metered consumption.	11	6	20	20	6	40
4.29	Billed unmetered consumption (kL/property/month)	The estimated average monthly consumption of properties that are metered but not billed based on their actual consumption.	-	-	-	30	15	45
4.30	Illegal consumption (kL/property/month)	Illegal connections include all properties that will still have illegal or unregistered connections after installation of the new scheme. The number of properties with illegal connections has to be estimated. The	-	-	-	40	20	60

		model will automatically assume the number of illegal connections to be the total number of properties minus the numbers of billed metered and billed unmetered properties.						
4.31	Total/average	The total number of properties included in the analysis is calculated as the sum of the billed metered, billed unmetered and illegal connections. The number of properties has to equal the number of properties (entered under global input parameters).	-	-	-			
4.32	No of meters installed	The number of meters to be installed in the proposed scheme. It is assumed that existing billed metered consumers will have their meters replaced and that all other consumers will move to the billed metered consumption category.	-	-	-	-	-	-
Fraction of properties paying for water								

4.33	Billed metered consumption	Fraction of billed metered properties currently paying their full water bill for the conventional and advanced meter options respectively.	75	50	85	50	10	90
4.34	Billed unmetered consumption	Fraction of billed unmetered properties currently paying their full water bill for the conventional and advanced meter options respectively.	50	0	100	25	0	100
4.36	Ave time between meter readings (months)	How frequently water meters will be read in the new scheme. Ideally meters should be read every month, and the frequency should not be less than every three months.	2	1	3	2	1	3

The expected ***Billed metered consumption*** (Item 4.24) includes all properties that are metered and billed based on their actual consumption. The number of properties and their estimated average monthly consumption. The fraction of properties on this item is equivalent to the one in item 3.5.

The typical expected billed metered consumption of 12 and 10 KL/property/month is selected for conventional and prepaid meters respectively. The figures range from 3 to 15kl/property/month.

As cited by Couvelis & van Zyl (2012), Frame et al (2009) indicated that 62% of 8 000 low income properties of Cape Town had on-site leakage prior to a water leakage repair program and through the program, consumption was reduced from 19 kl/month/property to 11.5 kl/month/property. This translates to a percentage of 40%. As outlined in item 3.8, the typical fraction of consumption that is onsite leakage is selected as 40% which coincides with the percentage reduction obtained in low income properties of Cape Town. It is reasonable that after installation prepaid meters the fraction of consumption that is onsite leakage can be reduced to 10% while the overall consumption is reduced by 20% but not lower than 6 kl (FBW). Thus the typical, low and high values are selected to be 6 kl, 11 kl and 20 kl respectively after implementation of prepaid meters while they remain as in item 3.1. in the case where conventional meters are installed.

The ***Billed unmetered consumption*** (Item 4.25) includes all properties that are not metered but are billed for water consumption, or are metered but not billed based on their actual consumption. Billed unmetered properties will normally be billed a flat rate for their water consumption. The number of properties is as shown on item 3.6.

The typical average monthly consumption for the billed unmetered properties of 30 kl/property/month is selected since the results of the practitioners' survey indicate that the figure ranges from 15 kl to 45 kl/property/month. In the current situation parameters billed unmetered consumption (item 3.2), it was deduced that the typical, low and high values are selected to be 30 kl, 15 kl and 50 kl/property/month. This values cannot be expected to change with the type of metering installed. Thus the typical, low and high values for billed unmetered consumption are selected to be 30 kl, 15 kl and 50 kl/property/months for both conventional and prepaid meters. However, since the evaluation focuses on the scheme, it is highly unlikely that prepaid meters are installed yet consumers are stilled billed a fixed rate. That negates the whole essence of metering. Thus this component of consumption is assumed to be zero.

The ***Illegal consumption*** (Item 4.26) average monthly consumption for properties with illegal connection.

The illegal consumption when conventional meters are installed is expected to be the same as in the current situation; item 3.3 of which the typical, low and high values for illegal consumption were selected to be 40 kl, 20 kl and 60 kl/property/month. These values cannot be expected to change with prepaid meters. However, since the evaluation focuses on the scheme and it is based on an idea situation where the meters can be monitored in a way that illegal connections are not present. Thus this component of consumption is assumed to be zero.

The ***Total/average*** (Item 4.27) is the summation of the above 3 mentioned categories of consumption

The ***No of meters installed*** (item 4.28) is the number of meters to be installed in the proposed scheme. It is assumed that existing billed metered consumers will have their meters replaced and that all other consumers will move to the billed metered consumption category.

The ***fraction of Billed metered consumers currently paying for water*** (Item 4.29) is the fraction of consumers without arrears.

According to the practitioners' survey, the fraction of billed metered consumers paying for water ranges from 0 % to 100 % for both conventional and prepaid meters. With conventional meters installed the values are expected to be similar to the current situation in item 3.5. Thus with conventional meters, the typical, low and high values for fraction of billed metered consumers paying for water are selected to be 50 %, 10 % and 90 % respectively while with prepaid meters the typical, low and high values are selected to be 75 %, 50 % and 85 % respectively.

The ***Ave time between meter readings*** (Item 4.31) is the frequency at which the meters will be read in the scheme. Ideally meters should be read every month, and the frequency should not be less than every three months.

The typical average time between meter readings of once per month or monthly is selected since results of the survey indicate that the frequency ranges from monthly to quarterly. These values are assumed to be applicable to conventional metering and not prepaid meters. However, the same values can be used but it should be noted that with prepaid meters, meter reading is not done for billing purposes and can be done once a year just as a routine inspection for illegal connections and checking the accuracy of the sales collection.

3.3.3. Evaluation framework: results

Introduction

This section describes the results of the advanced meter evaluation system provided in the accompanying excel spread sheet model. These results of the evaluation are shown on the 'Results' tab and several calculations are presented in the results in four categories: technical, social, environmental and economic.

In this evaluation no attempt is made to reduce the project recommendation to a single value or score. Reducing a multi-faceted and complex problem to a single value can only be misleading by oversimplifying the problem.

The approach followed in this evaluation framework was to estimate critical performance parameters aimed at assisting the designer to make rational decisions. To assist the designer, certain cells are formatted to highlight particularly good or bad values.

As a general rule, a result highlighted as 'Very bad' indicates a critical failure that should result in the system being rejected. Results formatted as 'Unrealistic' indicate that the result should not be trusted and that the input parameters should be checked to correct this problem. Table 13 shows the formatting of the results' cells.

Table 13: Key to project evaluation results

Very bad
Bad
Neutral
Good
Very good
Unrealistic
Take note of value

The results of the analysis are discussed in the rest of this chapter under the following headings:

- Technical

- Social
- Environmental
- Economic

Technical

The technical result of the metering technology evaluation is an indication of how the robustness of the technology makes the technology suit the application. For the purpose of this study it is based on compliance to national standards and the meter replacement requirement.

SABS compliance: It is a legislative requirement that water meters are compliant to South African National standards. Conventional meters are expected to comply with SANS 1529-1 while electronic and prepaid meters are expected to comply SANS 1529-9 as stated earlier in the report. Compliance is assumed.

Number of meters to replace: This is the average number of failed meters to be replaced per month depending on the life span of the water metering technology and the failure rate. This is the figure obtained from adding all meters having to be replaced due to each type of failure-i.e. vandalism, mechanical failure or electronic failure.

Social

The social result of the technology evaluation gives the framework user an indication of the potential problems regarding public acceptance of the metering technology to be implemented chiefly on the ability and willingness to pay.

Environmental

This environmental result gives an indication of the potential reduction in water consumption; discouraging the wasteful use; and the number of batteries to dispose every year.

Reduction in consumption: The respective reduction in consumption if the proposed conventional and advanced water metering systems are implemented.

One of the most important reasons for implementing advanced water metering technology is reduction in consumption. When consumers are aware of their consumption and billed accordingly, they are incentivised to use water more sparingly.

Disposal of batteries The average number of batteries that will need to be safely disposed if the advanced water metering is implemented. An environmental concern surrounding batteries is the impact they have at the end of their lives as they end up in landfills, where the most serious problem starts. As batteries are made of different chemicals to power their reactions, some of the chemicals, such as nickel and cadmium are extremely toxic and can cause damage to humans and the environment. In particular, they can cause soil and water pollution and endanger wildlife. For example, cadmium can cause damage to soil micro-organisms and affect the breakdown of organic matter. It can also bio-accumulate in fish, which reduces their numbers and makes them unfit for human consumption (AlAbdulkarim, Lukszo & Fens, 2012). The extent of the damage is greatly influenced by battery type and its capacity (AlAbdulkarim, Lukszo & Fens, 2012), and this should be investigated in the design phase of the project.

Economic

The economic result of the evaluation framework gives an indication of financial viability of the metering system to be implemented. This is achieved through determining the payback period for the technology and the effective surplus to be expected from the implementation. Variables relevant to determination of the payback period and the effective surplus of the installation.

Capital payback period: The payback period is the time required to recover the initial investment of purchasing and install the metering technology, calculated from the income generated by the meter. This payback period for investment can also be thought of as time required for cumulative returns to equal cumulative costs. In the case where the meter replaces an existing meter, only additional income is taken into consideration.

With other variables being the same, the water metering technology with investment that can be repaid in a shorter time period should be considered the better choice. The shorter time period implies that investment costs are recovered sooner and present less risk of financial loss. This payback period can be calculated as the difference between the total above mentioned financial benefits and the associated costs.

This item is obtained through dividing the total capital cost by increased operational surplus obtain as outlined in the above subsection.

Effective surplus: The effective surplus is the average monthly surplus over the lifespan of the meter, incorporating capital and operational costs. It allows meters with different service lives to be compared on the same basis. For instance, a more expensive type meter may result in higher monthly income from water sales. Thus even though these meters may be more expensive to install, have shorter service lives and a longer capital payback period, the increased income may be high enough to make the effective surplus of these meters higher than the alternative.

3.3.4. Typical low income scenario

The typical low income scenario is a situation in which the low income scheme is evaluated using typical values for the input parameters.

Technical results

The technical results of the evaluation framework for a typical low income scheme indicates compliance to the SABS standards for both conventional and prepaid meters with a significant difference between the numbers of meters to be replaced per month. This significant difference is due to a higher failure rate and low life span of prepaid meters. Table 14 shows the typical technical results for low income scheme.

Table 14: Technical result for typical low income scheme:

1. TECHNICAL			
No	Property	Conventional metering (baseline)	Advanced metering
1.1	SABS compliance	Yes	Yes
1.2	Number of meters to replace (/month)	**7**	**23**

Social results

The social results of the evaluation work are an indication of the social factor prevailing in the community in which the proposed scheme is to be implemented. This results give an indication on level of public acceptance to the scheme. Table 15 shows the social result of a typical low income community.

As shown in Table 15indicate the values of the factors grey except for water bill as a fraction of income. The values appearing in grey means that the values are just acceptable. However, water bills make up 13.1% of family income. This fraction is not too high but since it is higher than 5%, the ability to pay may be a problem as studies indicate that consumers are able and willing to pay for a water bill not higher than 5% of the household income.

Table 15: Social result of the typical low income community

2. SOCIAL		
No	**Property**	**Value**
2.1	Current rate of meters vandalised (/year)	3.0%
2.2	Unemployment rate	50.0%
2.4	Volatility of community (No of protest or mass action incidences per year)	3
2.5	Average water bill (/month)	R394.32
2.6	Average property income (/month	R3 000.00
2.7	Water bill as a fraction of income	13.1%

Environmental results

The environmental result shows the environmental impact that the proposed scheme has a potential to bring. The major aspect of this environmental impact to be brought by the proposed scheme is mainly the percentage reduction in consumption (including leakage) and the number of batteries to be disposed. Table 16 shows the environmental impact of the proposed scheme in typical low income community.

Table 16 indicates that implementing conventional meters has a potential to lead to an acceptable reduction in consumption of 25% while implementing prepaid meters in low income communities has a potential to lead to a very good percentage reduction in consumption of about 60%. It is worth noting that percentage reduction in consumption is significantly affected by the assumption that after implementation of the scheme, all properties in the scheme are billed based on metered consumption meaning that the billed unmetered consumption and illegal consumption are assumed to be nil after implementation of the scheme.

The number of batteries to dispose annually are expected to be 0 because conventional meters are assumed not to have batteries while implementation of prepaid meters indicate that 167 batteries will have to be replaced annually in a scheme where 1000 prepaid meters are installed.

Table 16: Environmental result of the typical low income scheme

3. ENVIRONMENTAL					
No	Consumption	Units	Current	Conventional metering (baseline)	Advanced metering
3.1	Billed metered consumption	(kL/month)	10000	20000	11000
3.2	Billed unmetered consumption	(kL/month)	9000	0	0
3.3	Illegal consumption	(kL/month)	8000	0	0
3.4	Total consumption	(kL/month)	27000	20000	11000
3.5	Unit consumption	(kL/property/month)	27	20	11
3.6	Reduction in consumption	(kL/month)		7000	16000
3.7	Fractional reduction in consumption	-		25.9%	59.3%
3.8	No of batteries to dispose	(/year)			167

Economic results

The economic results of the proposed scheme indicate the financial viability of the proposed scheme. The key parameters indicating the financial viability of the proposed scheme are capital payback period and effective surplus. Table 17 shows the financial impact that can be expected from moving from the current system to the proposed scheme where either conventional or prepaid meters are installed,

According to van Kooten (2016), the payback period is the point in time when a project's total benefit equals the capital cost; that the time required for the project to pay back its initial capital cost while the effective surplus is the annual profit that the project makes during its lifespan (van Kooten, 2016). Either of these two may be used to compare the financial benefits of the scheme. The payback period is the measure on how risky it is to get back the capital injected in the project while the effective surplus gives an indication of the profitability of the scheme. In low income schemes where the social factors hugely affect the public resistance, the payback period would serve as a realistic basis of comparisons between schemes.

Table 17 shows that in a typical low income scheme where 1000 properties are covered, the current system has a negative operational surplus of R 100 525. This indicates that implementing conventional meters could lead to a reduction in that negative operational surplus of about R 10 000 and R 30 000 on installation of conventional and prepaid meters respectively. Even though both implementation of conventional and prepaid meters still leads to a negative operational surplus, there is an apparent increase. The economic results of the evaluation of a typical low income scheme indicate that conventional meters have a capital payback period of

4.4 months while prepaid meters have a capital payback period of 32 months. This basically means that installation of conventional meters about 5 months will be required to achieve the change in operational surplus from R 100 525 to R 9 967 while for installation of prepaid meters, about 32 months will be required to achieve the change in operational surplus from R 100 525 to R 31 754.

The effective surplus of R 1 060 083 and R 605 247 expected from implementation of conventional and prepaid meters respectively. It is worth noting that this is not an absolute effective surplus but rather apparent effective surplus. This is just the effective difference in the current situation and the proposed scheme. It might happen that the scheme makes a loss but the loss is significantly better than the loss in the current situation.

Table 17: Economic viability of a proposed scheme in typical low income scheme

4. ECONOMIC					
No	**Income**	**Units**	**Current**	**Conventional metering (baseline)**	**Advanced metering**
4.1	Billed metered consumption	(/month)	R63 600.00	R127 200.00	R104 940.00
4.2	Billed unmetered consumption	(/month)	R24 000.00	R0.00	R0.00
4.4	Total income	(/month)	R87 600.00	R127 200.00	R104 940.00
4.5	Unit income	(/property /month)	R87.60	R127.20	R104.94
4.6	Increased income	(/month)		R39 600.00	R17 340.00
4.7	Fractional increased income			45%	20%
	Capital cost				
4.8	Water meters		R0.00	R200 000.00	R1 500 000.00
4.9	Installation		R0.00	R200 000.00	R500 000.00
4.11	Communication infrastructure cost		R0.00	R0.00	R120 000.00
4.12	Payment infrastructure cost		R0.00	R0.00	R80 000.00
4.13	Total capital cost		R0.00	R400 000.00	R2 200 000.00
4.14	Unit capital cost	(/property)	R0.00	R400.00	R2 200.00
	Operational cost				
4.15	Water production	(/month)	R162 000.00	R120 000.00	R66 000.00
4.16	Meter reading	(/month)	R625.00	R1 500.00	R833.33
	Meter operation & maintenance	(/month)	R1 500.00	R3 000.00	R20 000.00
4.17	Billing cost	(/month)	R8 000.00	R10 000.00	R0.00
4.18	Billing system operating cost	(/month)		R0.00	R0.00
4.19	Communication system operating costs	(/month)			R0.00
4.21	Failed meter replacement cost	(/month)	R16 000.00	R2 666.67	R45 000.00
4.22	Battery replacement cost	(/month)			R4 861.11
4.23	Total operating cost	(/month)	R188 125.00	R137 166.67	R136 694.44
4.24	Unit operating cost	(/property /month)	R235.16	R137.17	R136.69
4.25	Decreased operating cost	(/month)		R50 958.33	R51 430.56
	Summary				
4.26	Operational surplus	(/month)	**-R100 525.00**	**-R9 966.67**	**-R31 754.44**
4.27	Increased operational surplus	(/month)		**R90 558.33**	**R68 770.56**
4.28	Capital payment period	(months)		4.4	32.0
4.29	Expected service life	years		15	10
4.30	Effective surplus	(/year)		R1 060 033.3	R605 246.7

3.4. Sensitivity analysis

3.4.1. Introduction

The main objective of the sensitivity analysis was to determine the level of influence of the different input parameters on the outcomes of the evaluation results as calculated by the framework spreadsheet model. The impact of the different input parameters is tested on the selected results parameters. In this exercise, for each input parameter, the typical, low and a high value were used to determine this impact. Impact on the following results parameters were tested:

- Payback period
- Effective surplus
- Reduction in consumption
- Number of batteries to be disposed

The test was through varying the input parameters across the selected typical, low and low values.

3.4.2. Payback period

The graphs represented below show the way in which the capital payback period of prepaid and conventional meters is affected by different input parameters. The input parameters were tested and their values ranging between low, typical and high values as presented in the table below.

For prepaid meters the capital payback period is found to range from 15 months to 58 months while that of conventional meters range from -29 to 10 months. The negative payback period implies that the payback period will never be reached meaning that the capital invested in the scheme will not be recovered at all.

This capital payback period for prepaid meter scheme is significantly affected by the following input parameters:

- Billed metered consumption payment level (fraction of billed metered consumers paying for water);
- Billed metered consumption level (amount of water consumed by billed metered consumers);

- Meter failure rate;
- Meter price;
- Billed unmetered consumption payment level and
- Water cost price.

Increasing the fraction of billed metered consumers paying for rent, increasing the consumption level of billed metered consumers, and increasing the fraction of billed unmetered consumers paying for water leads to a significant decrease in capital payback period and vice versa, while decreasing the meter failure rate; meter price and water cost leads to an increased capital payback period for prepaid meters and vice versa. Figure 10shows the capital payback period for prepaid meters.

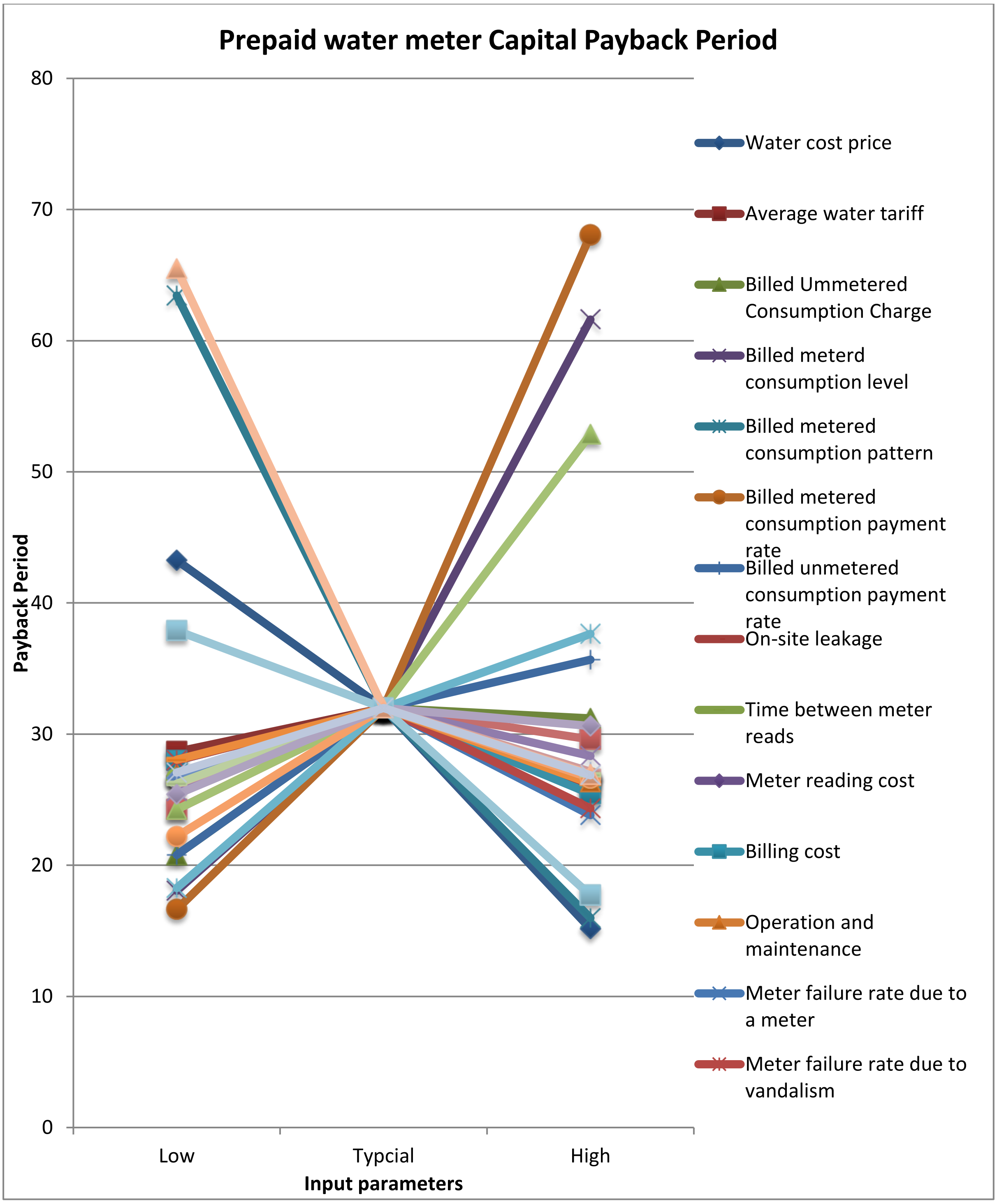

Figure 10: Capital payback period for prepaid meters

On the one hand, the capital payback period for a conventional water metering scheme is significantly affected by the following input parameters:

- Billed metered consumption payment level;
- Billed metered consumption level;
- Installation cost and

- Water cost price.

In the same way as with prepaid meters, increasing the consumption payment level and increasing the billed metered consumption level leads to a significant decrease in a capital payback period for conventional meters and vice versa. Decreasing the installation cost and water cost price lead to a significant decrease in capital payback period of conventional meters and vice versa.

The capital payback period for prepaid meters is always higher than that of conventional meters except in cases where the billed metered consumption for conventional meters is so low that the capital injected into the scheme will never be recovered. The capital payback period of prepaid meters being higher than that of conventional meters implies that is implementing a prepaid meter scheme has come with a higher risk of losing the capital than conventional meters. However, this does not necessarily imply that conventional meters are more profitable to implement than conventional meters. Figure 11 shows the capital payback period for Conventional meters

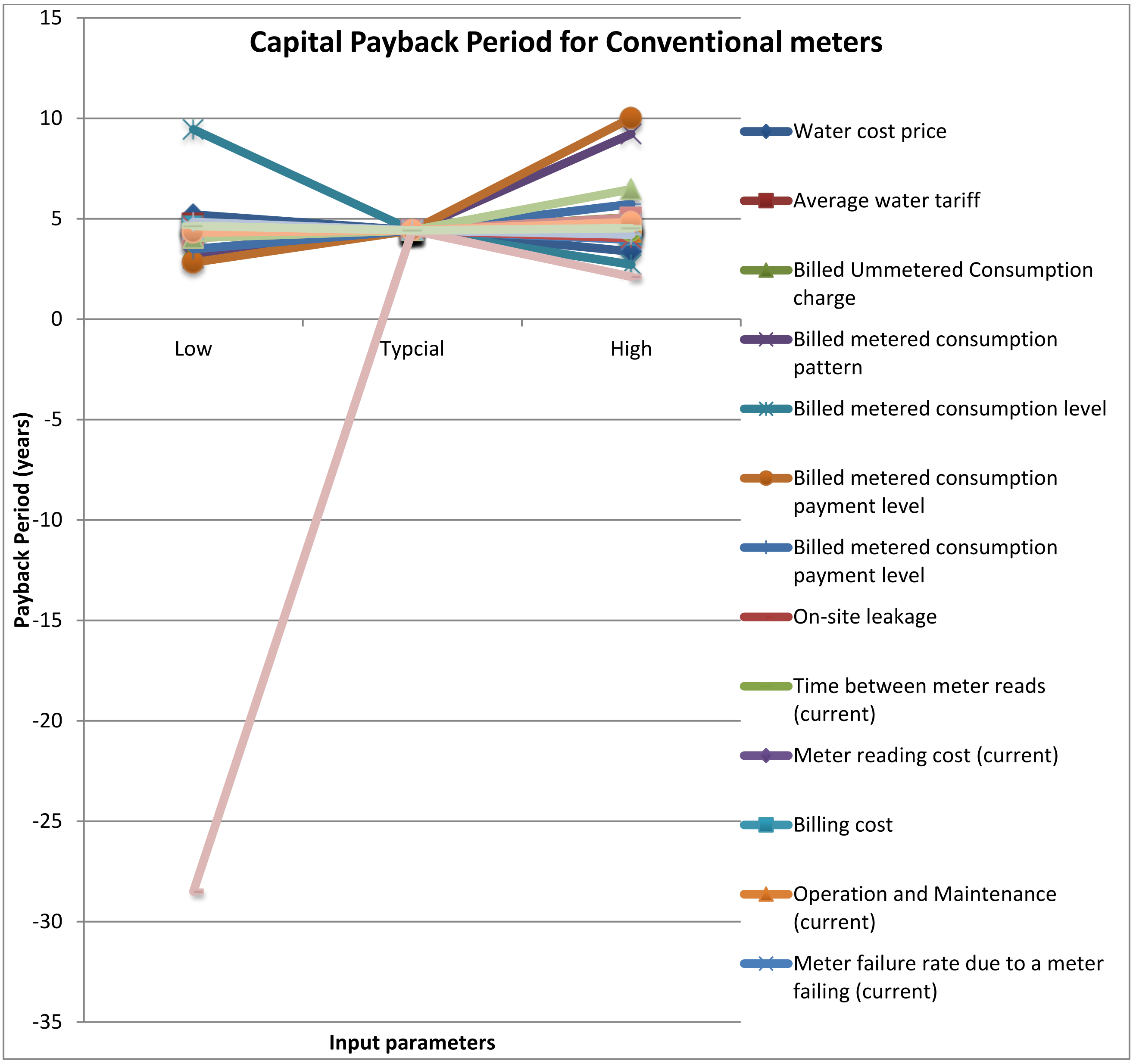

Figure 11: Capital payback period for conventional meters

3.4.3. Effective surplus

The graphs shown in Figure 12 and Figure 13 are represented show the way in which the effective surplus of prepaid and conventional meters is affected by different input parameters. The input parameters were tested and their values ranging between low, typical and high values as presented later in this section.

For prepaid meters, the effective surplus is found to range from R 170 924 to R 1 549 484 while that of conventional meters range from an effective deficit of R 195 084 to an effective surplus of R 2 247 153. The negative effective surplus implies that implementing the conventional scheme will cost the municipality R 195 084 more to supply the consumers in the scheme with water as compared to the current situation (prior) to implementation.

For prepaid meters the effective surplus is significantly affected by the following input parameters:

- Water cost price;
- Billed metered consumption level;
- Billed metered consumption payment level;
- Meter failure rate;
- Meter service life;
- Meter price and
- Installation cost.

Decreasing the water cost price, meter failure rate, meter price and installation cost leads to an increase in effective surplus for prepaid water meter schemes and vice versa while increasing the consumption of billed metered consumers and the fraction of billed metered consumers paying for water leads to an increase in effective surplus for prepaid water schemes. Figure 12 shows the effective surplus of prepaid meters.

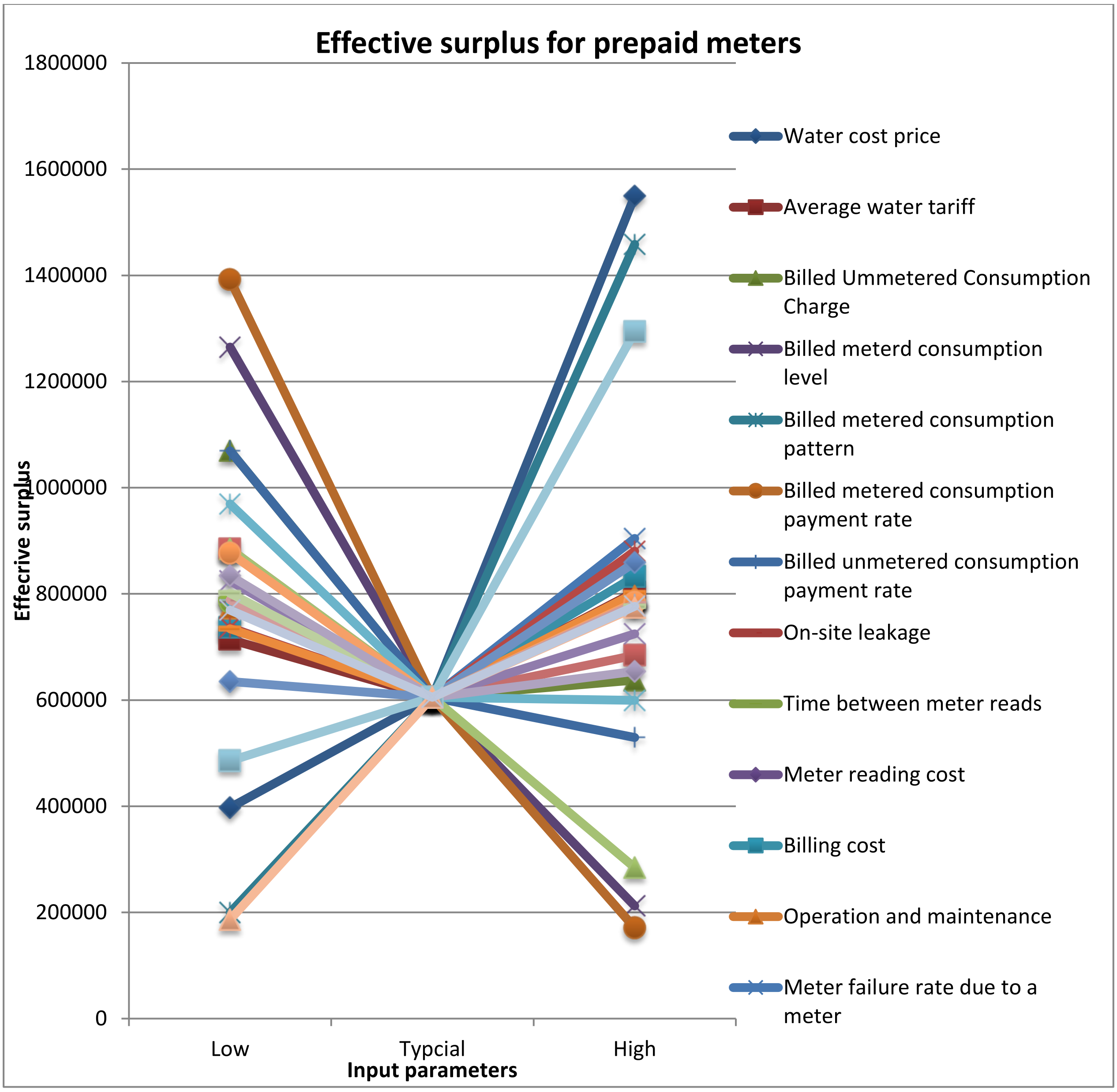

Figure 12: Effective surplus for prepaid meters

For conventional meters the effective surplus is significantly affected by the following input parameters:

- Billed metered consumption payment level;
- Billed metered consumption level;
- Water cost price;
- Meter failure rate;
- Billing cost

Increasing the billed metered consumption payment level; billed metered consumption level leads to an increase in effective surplus for conventional meters and vice versa while decreasing the water cost price, meter failure rate and the billing cost leads to an increase in effective surplus for conventional meters and vice versa. Figure 13 shows the effective surplus of conventional meters.

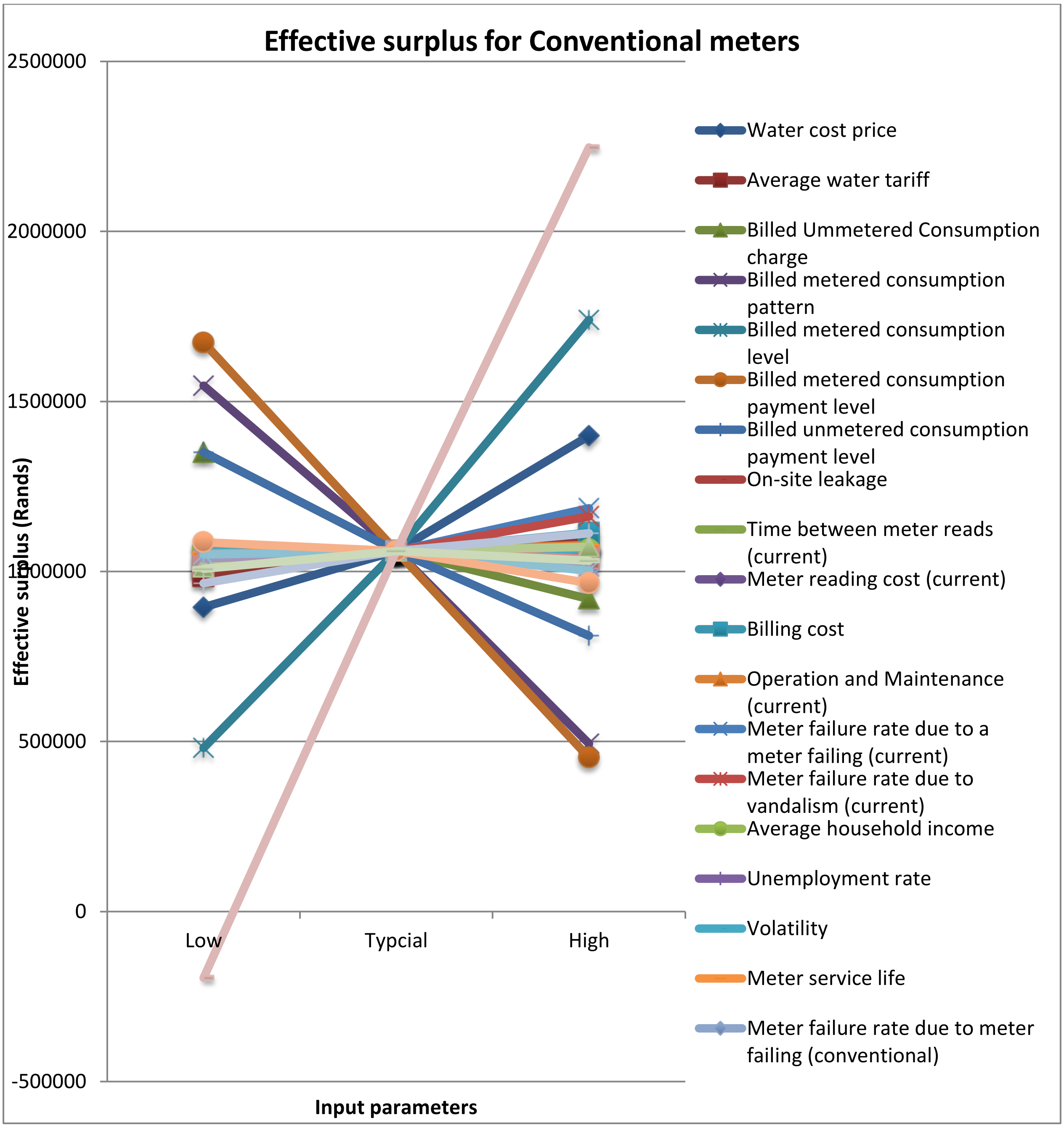

Figure 13: Effective surplus or conventional meters

The effective surplus for prepaid meter schemes tend to be usually higher than that of conventional meters except for instance where the billed metered consumption payment level and or the billed metered consumption level is approaching the highest value. Having these two parameters close enough to the high value, it will be the sensible thing to go for conventional meters instead of prepaid meters. On the one hand, having these two parameters close enough to the low values will make prepaid meters better than conventional meters in terms of the effective surplus. On the other hand, having the payment level close enough to the low value will make conventional meters undesirable due to the potential deficit making prepaid meters the desirable option to take.

3.4.4. Reduction in consumption

The graphs represented below show the way in which the reduction in consumption resulting from implementation of prepaid and conventional meters is affected but different input parameters. The input parameters were tested and their values ranging between low, typical and high values as presented later in this section.

For prepaid meters the resulting reduction in consumption is found to range from 4% (0.04) to 78% (0.78) while that of conventional meters range from an increase of 74% (0.74) to a reduction of 78% (0.78). This implies that prepaid meters generally lead to a decrease in consumption level while conventional has a potential to lead to an increase in consumption depending on the current and expected consumption patterns and levels.

As shown in Figure 14 and Figure 15; for both prepaid meters and conventional meters the reduction in consumption is only affected by the billed metered consumption (current and expected). The potential reduction in consumption due to implementation of prepaid meters is usually higher than that due to conventional meters. This fractional reduction is dictated by the difference in current and expected consumption level.

Prepaid meters tend to lead to reduction in consumption no matter what the consumption levels are while for conventional meters if the current and the expected consumption levels approach the low values, it turns out that this leads to an increase in consumption instead of reduction in consumption. Thus in the cases where the billed consumption is close enough to the low value, prepaid meters will be a better option to implement as compared to the conventional meters. It also shows that under any similar circumstances, prepaid meters will result in a better reduction in consumption as compared to the conventional meters.

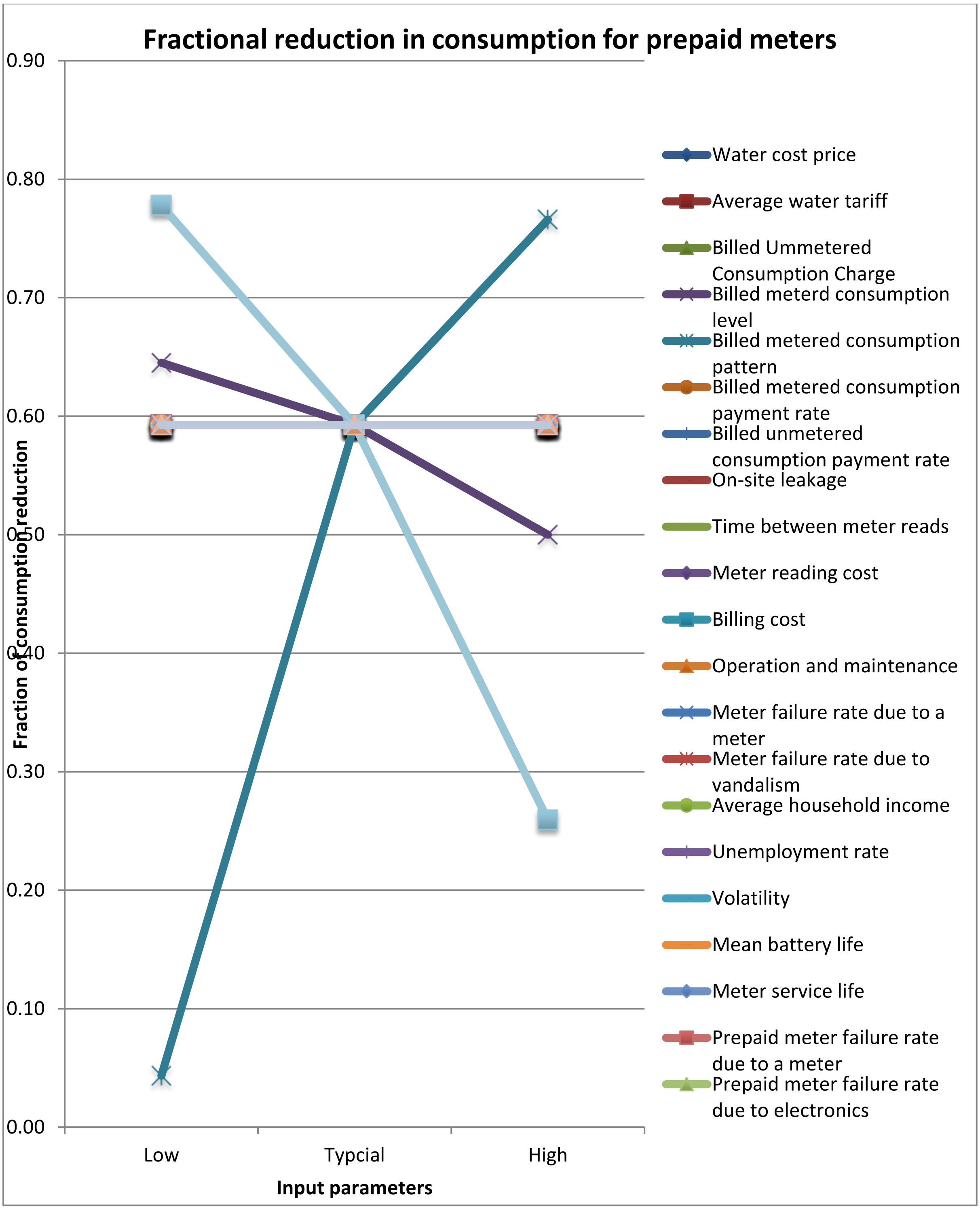

Figure 14: Fractional reduction in consumption for prepaid meters

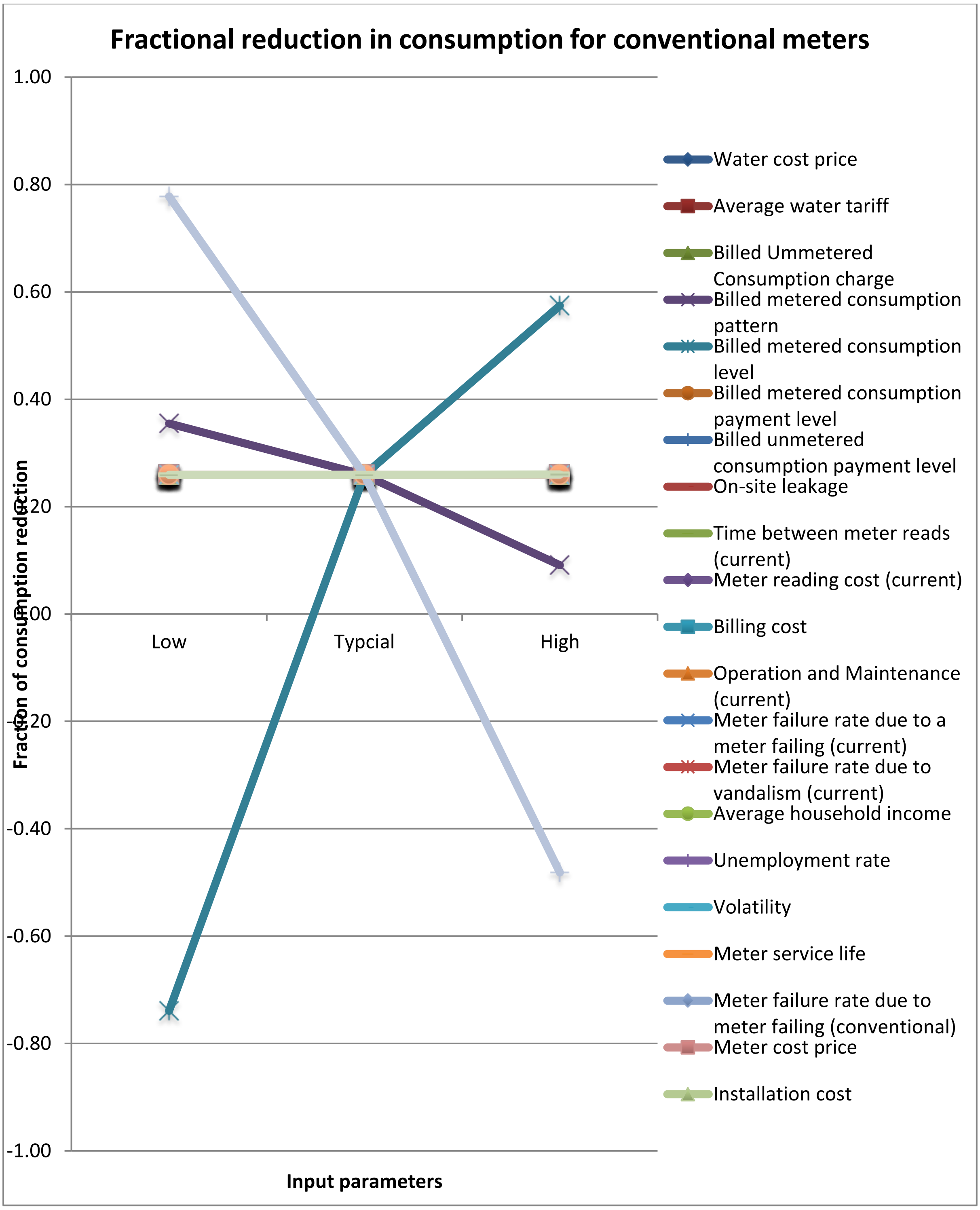

Figure 15: Fractional reduction in consumption for conventional meters

3.4.5. Number of batteries to dispose

The graph represented below show the way in which the number of batteries to be replaced each year resulting from implementation of prepaid is affected but different input parameters. The input parameters were tested and their values ranging between low, typical and high values as presented later in this section. It is worth noting that conventional meters do not require batteries to operate and therefore the number of batteries is expected to be nil at every instance.

The number of batteries to replace each due to implementation of prepaid meters in a scheme of 1000 connections ranges from 111 to 333 depending on the input parameters. As shown in Figure 16, the number of meters to replace annually depend on the mean battery life only. Thus conventional meters are always environmentally friendlier in this regard.

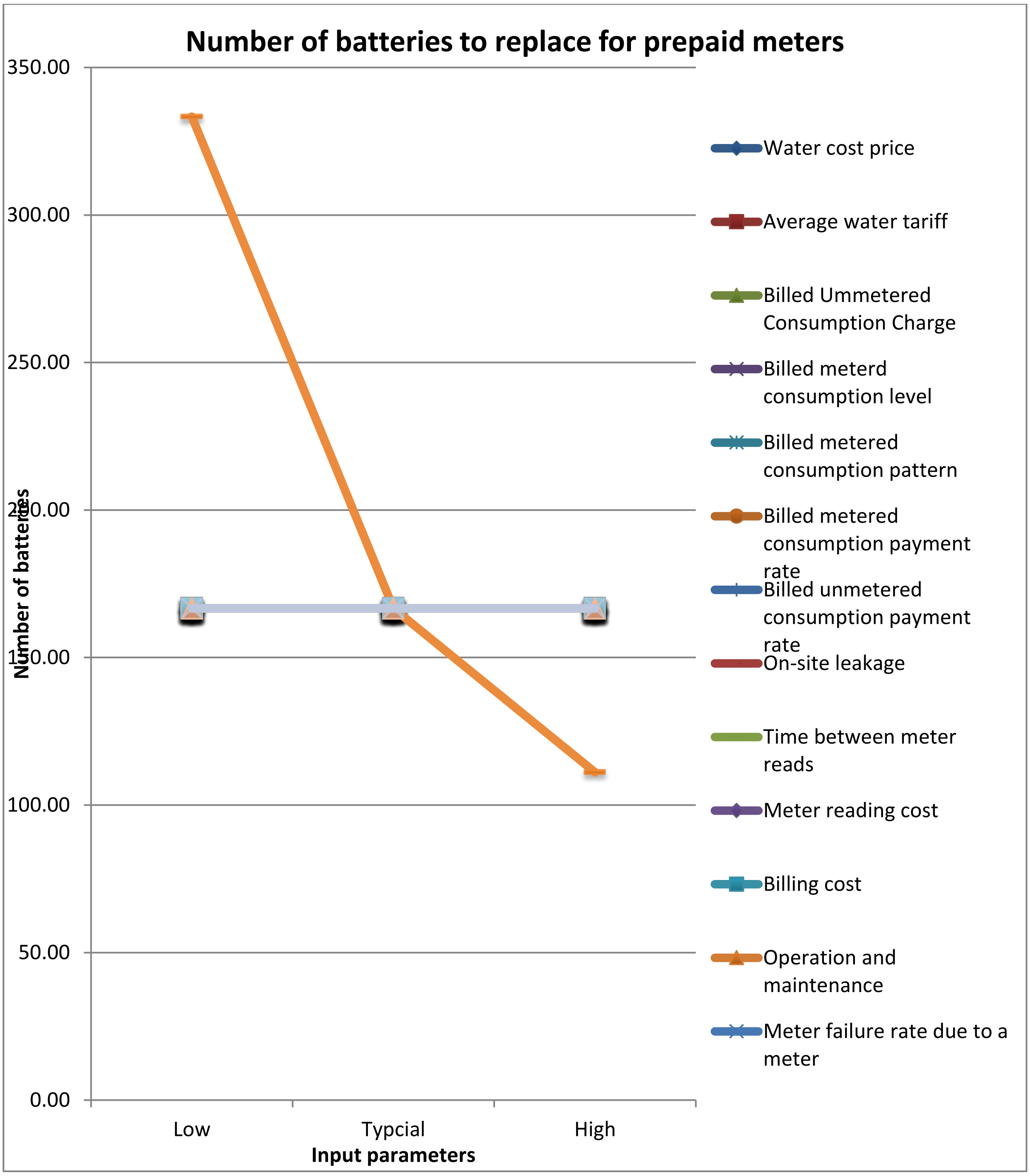

Figure 16: Number of batteries to dispose in a prepaid metering scheme

4. CASE STUDY EVALUATION

4.1. Introduction

In this chapter, the prefeasibility study of prepaid meters in eThekwini is evaluated based on the information and data obtained from the status quo outlined in the report together with the typical values suggested in Chapter 3. The comparison between the findings on this study and the findings obtained by the engineering consultant is also made.

4.2. EThekwini feasibility study

From the terms of reference of the feasibility study for the use of prepaid/alternative domestic metering solutions it has been made clear that the objective of the EThekwini municipality is cost recovery. However, debt recovery is a secondary objective. The municipality needed the metering technology that can help address the two challenges and serve as tools for cost recovery while at the same time recovering the previous debts that low consumers had.

4.2.1. Technology validation for EThekwini feasibility study

Like the above schemes implemented with an objective of cost recovery the metering technology was tested to check that the proposed technology has all the necessary features to serve as tool for cost recovery. In addition to the features necessary for the technologies to serve as tools for cost recovery, for debt recovery, the metering system should have the above capabilities but is also required to have the ability to be programmed to charge variable rates that incorporate debt repayment as well as water payments. The validation results are shown in Table 18.

Table 18: Cost recovery and debt recovery validation

Requirement	Prepaid	Conventional	Onsite billing
A shut-off or flow restriction valve	Meets requirement	Meets requirement	Does not meet requirement
Ability to shut off or restrict flow when credit runs out	Meets requirement	Does not meet requirement	Does not meet requirement
Ability to provide the minimum FBW	Meets requirement	Meets requirement	Meets requirement
Proven tamper protection or alarms	Meets requirement	Meets requirement	Meets requirement
Ability be programmed to charge variable rates that incorporate debt repayment	Meets requirement	Does not meet requirement	Does not meet requirement

5.2.2. Detailed evaluation of EThekwini feasibility study

The evaluation process was a comparison of conventional metering and prepaid metering, where conventional metering was set as a benchmark. It is worth noting that even though the project covered the eThekwini low income area, the results of the evaluation are for every 1000 meters installed. The results of the evaluation are as shown in the Table 19:

The technical results of both conventional and prepaid metering highlighted in green indicate that the two technologies are both technically suitable as they are both SABS compliant. However, prepaid metering is less robust and therefore requires more technical support and also requires a higher number of meters to be replaced every month. The results imply that if a municipality installs conventional meters, the expectation is that 7 meters will be replaced every month while 23 meters will be expected to be replaced if prepaid meters are installed. For both conventional and prepaid meters the number of meters to be replaced every month are in a white-coloured cells meaning that both this numbers are acceptable even though the number is higher for prepaid meters. The reason behind this significant difference is the difference in service lives and the meter failure rates. It follows that installing any of the two technologies is a technically feasible option for eThekwini.

Table 19: Technical evaluation results

1. TECHNICAL			
No	**Property**	**Conventional metering (baseline)**	**Advanced metering**
1.1	SABS compliance	Yes	Yes
1.2	Number of meters to replace (/month)	**7**	**23**

Table 20 shows the social evaluation results of the eThekwini prefeasibility study.The numbers in red indicate that the social factors do not favour metering as the water bill make up 11.1% of the average household income per month. These factors indicate that the willingness and ability to pay may be quite low. The FBW of 9kl per month subsidised by the National Treasury leaves the consumer having to pay for consumption in access of FBW. Taking the expected average unit consumption of 12.35 kl/property/month implies that the 9 kl are free to the consumers while the consumers are left with 3.35 kl to pay for. Thus the consumer will have to pay about R 45.00 per month to the municipality for the consumption in access of the FBW. This makes a consumer pay about 2 percent of the average household income which is less than 5% of the average household income. This is an indication that the ability to pay will not be a problem. This coincides with the findings by GIBB Consulting that ability to pay is not a problem in the area (GIBB, 2015). The 9 kl FBW plays a significant role in making the water bill affordable. Contrary to the findings of the prefeasibility study of GIBB Consulting, consumers are still in arrears. But the reasons are outlined to be poor cadastral arrangement and formal address.

Table 20: Social evaluation results

2. SOCIAL		
No	**Property**	**Value**
2.1	Current rate of meters vandalised (/year)	3.4%
2.2	Unemployment rate	50.0%
2.4	Volatility of community (No of protest or mass action incidences per year)	3
2.5	Average water bill (/month)	R333.70
2.6	Average property income (/month	R3 000.00
2.7	Water bill as a fraction of income	11.1%

As seem in Table 21, the environmental impact of implementing conventional meters is acceptable as the fractional reduction in consumption is in a white the impact of implementing prepaid meters is very good for as it is in a green cell. Implementation of conventional meters has a potential to result about 28% reduction in consumption while installation repaid meters has a potential to result in about 40% reduction in consumption. Even though these two technologies have a potential to reduce consumption, prepaid water meter will be a better option to implement since the challenge face by eThekwini municipality is the high level of Non-Revenue Water in the area. On the one hand it is worth noting that the potential reduction in consumption entirely based on the expectation that after implementation of the scheme, all connections in the scheme will be billed based on metered consumption. For the municipality to achieve this significant reduction in consumption it is important that necessary effort and measures are taken to put illegal consumption to a minimum. Otherwise the benefit will be negated. On the other hand, it is worth noting that prepaid meters have a negative environmental impact because of the number of batteries to dispose annually. However, this number of batteries to be replaced annually is acceptable and cannot really dictate the choice of the technology.

Table 21: Environmental evaluation results

3. ENVIRONMENTAL					
No	Consumption	Units	Current	Conventional metering (baseline)	Advanced metering
3.1	Billed metered consumption	(kL/month)	9590	13700	11000
3.2	Billed unmetered consumption	(kL/month)	5480	0	0
3.3	Illegal consumption	(kL/month)	4000	0	0
3.4	Total consumption	(kL/month)	19070	13700	11000
3.5	Unit consumption	(kL/property/month)	19.07	13.7	11
3.6	Reduction in consumption	(kL/month)		5370	8070
3.7	Fractional reduction in consumption	-		28.2%	42.3%
3.8	No of batteries to dispose	(/year)			167

Table 22 shows the economic evaluation results. The financial results indicate that implementation of conventional metering has a potential to result in a financial surplus of about R 560 000 while implementation of prepaid meters have a potential to result in a surplus of about R 382 000 relative to the current situation. Contrary to this findings, the outcomes of the GIBB consulting on the prefeasibility study indicated a Net Present Value of R -15 500 and R 22 300 for conventional and prepaid meters respectively. The difference lies in the fact that according to this study the result is only relative to the current situation while in the prefeasibility study by GIBB Consulting, the values were absolute figures.

The financial results also indicate that the capital payback period of 7.3 and 55.6 months are to be expected from implementation of conventional and prepaid meters. The payback period for conventional meters can be described as very good while for prepaid meters is acceptable. These makes conventional meters a better option to take. However, it is worth noting that the selection cannot be made entirely based on the financial viability. On the one hand, it is worth bringing to attention that the primary objective of eThekwini Municipality is to reduce level of NRW and a secondary objective of debt and cost recovery.

Table 22: Economic evaluation results

4. ECONOMIC					
No	Income	Units	Current	Conventional metering (baseline)	Advanced metering
4.1	Billed metered consumption	(/month)	R25 912.18	R37 017.40	R111 457.50
4.2	Billed unmetered consumption	(/month)	R6 000.00	R0.00	R0.00
4.4	Total income	(/month)	R31 912.18	R37 017.40	R111 457.50
4.5	Unit income	(/property /month)	R31.91	R37.02	R111.46
4.6	Increased income	(/month)		R5 105.22	R79 545.32
4.7	Fractional increased income			16%	249%
	Capital cost				
4.8	Water meters		R0.00	R150 000.00	R2 600 000.00
4.9	Installation		R0.00	R200 000.00	R500 000.00
4.11	Communication infrastructure cost		R0.00	R0.00	R120 000.00
4.12	Payment infrastructure cost		R0.00	R0.00	R80 000.00
4.13	Total capital cost		R0.00	R350 000.00	R3 300 000.00
4.14	Unit capital cost	(/property)	R0.00	R350.00	R3 300.00
	Operational cost				
4.15	Water production	(/month)	R94 396.50	R67 815.00	R54 450.00
4.16	Meter reading	(/month)	R553.00	R1 185.00	R833.33
	Meter operation & maintenance	(/month)	R2 100.00	R3 000.00	R20 000.00
4.17	Billing cost	(/month)	R9 000.00	R10 000.00	R0.00
4.18	Billing system operating cost	(/month)		R0.00	R0.00
4.19	Communication system operating costs	(/month)			R0.00
4.21	Failed meter replacement cost	(/month)	R21 560.00	R2 566.67	R69 750.00
4.22	Battery replacement cost	(/month)			R2 736.11
4.23	Total operating cost	(/month)	R127 609.50	R84 566.67	R147 769.44
4.24	Unit operating cost	(/property /month)	R141.79	R84.57	R147.77
4.25	Decreased operating cost	(/month)		R43 042.83	-R20 159.94
	Summary				
4.26	Operational surplus	(/month)	**-R95 697.32**	**-R47 549.27**	**-R36 311.94**
4.27	Increased operational surplus	(/month)		**R48 148.05**	**R59 385.38**
4.28	Capital payment period	(months)		7.3	55.6
4.29	Expected service life	years		20	10
4.30	Effective surplus	(/year)		R560 276.6	R382 624.5

Prepaid meters have a high capital payback period of about 5 years which indicates the high level of risk of losing the capital cost injected in the scheme. On the one hand the prepaid meter have a low effective surplus compared to conventional meters and this makes it less financial viable as compared to conventional meters. However, if the municipality can get to purchase prepaid meters that cost less; ensure that a higher payment rate is achieved and finding; and using the prepaid meters that have a lower failure rate can improve the capital payback period and effective surplus for prepaid meters and make it worth choosing over conventional meter.

5. CONCLUSION

This chapter summarizes the main findings of this study and discusses recommendations for further research work.

5.1. Summary of the study

The main aim of this study was to develop an evaluation framework to help municipalities in the selection of appropriate advanced metering technologies for installation in low-income communities. This was firstly achieved through determining the range of functionality available and developed for advanced water metering. Available technology categorized according to functionality was found to comprise mainly of conventional meters, automatic meter reading technology, advanced metering infrastructure, prepaid meters and water management devices. The latter two are the most commonly implemented technologies in low-income communities because of their consumption management capability and perceived ability to increase municipal revenue and hence usefulness as tools for cost recovery.

Secondly, the aim of the study was achieved through documenting case studies of successful and failed implementation of advanced water meters, including social perception. While there is a wide range of advanced metering technologies on the market, mostly prepaid and WMDs have been installed in low-income communities. Some projects were successful and some failed due to public resistance, linked to unwillingness and the inability to pay. However, the technical failure of technologies also played a role in the failure of projects as it led to public resistance as people stayed without water after meters failed.

Thirdly, an Excel spreadsheet model was created to evaluate different technologies on technical, social, environmental and economic grounds. The technical evaluation is an indication of compliance with national standards and maintenance and operational requirements; the social evaluation is an indication of the level of community acceptance for the technology and potential ability and willingness to pay; environmental evaluation is an indication of the efficiency in water demand management and the extent of environmental hazard of battery disposal; and economic evaluation is an indication of the effective surplus to be expected from the implementation of advanced metering technology as well as the payback period for implementation of the technology.

Outcomes of the evaluation of low-income projects indicate that the estimated effective surplus of advanced metering technology surpasses that for conventional meters; however, the payback period for advanced metering technology is much higher than that of conventional meters. Even though the evaluation results indicate that advance meters seem to have a significant surplus over conventional meters, the unfavorable social climate in low-income community may erode all the profitability potential for conventional meters as the ability and willingness to pay is quite low.

5.2. Main conclusions

While South African legislation demands that all consumer end points be metered, the choice of metering technology lies with the responsible municipality (van Zyl, 2011). It was found that the choice of metering technology for implementation in low-income communities has primarily been driven by the ability of the technology to increase municipal revenue, and secondarily to manage water consumption through limiting consumers’ consumption and leak detection.

The impact of metering on water consumption seems to be insignificant as long as consumers are not billed based on metered consumption, as then there is no incentive for consumers to manage their consumption. From a financial perspective, if consumers are charged a fixed amount for their consumption, the choice of meter installed does not have any significant impact on revenue generation; but the expenses of capital investment and operational and maintenance costs differ.

Even though municipalities in low income areas install prepaid meters in low income communities for cost recovery, prepaid meters can be in operation yet still not fulfill the requirement of increasing municipal revenue. The reason for poor collection of revenue is mostly because consumers manage to keep their consumption within FBW allocation. Keeping consumption within FBW allocation erodes the economic benefit of increasing municipal revenue and hence cost recovery. However, this indirectly serves as an economic benefit as reduced consumption results in reduced quantities of water to be treated and hence costs of abstraction and treatment.

Advanced water metering technology in low-income communities mostly show a higher potential effective surplus than conventional meters. However, conventional meters have a shorter payback period, making conventional metering a less risky investment than advanced metering technology. The potential for advanced meters leading to increased municipal revenue is put at stake by social factors in low-income communities. Public resistance, unwillingness and inability to pay hinder a rise in payment level of water services. On the other hand, forcing consumers to pay in a way to increase municipal income leads to vandalism which brings projects to a complete failure.

5.3. Recommendation for further research

Identifying projects and monitoring them from the planning up to the operational phase will help to achieve a more realistic model and hence more accurate estimation. Applying the framework at the planning phase of the project will determine the feasibility as well as expected performance, while applying it at the operational stage will determine the actual performance. Using results at different stages of the project will enable calibration of the model and hence yield more accurate results.

Since social factors have a significant (yet not quantifiable) impact on the success (or not) of the implementation of technologies, it is important that a study be done on quantifying the correlation between success of the implementation and the social parameters.

When studying the potential for advanced metering, it is important that framework parameters are actually tested, i.e. the parameter figures should not only be based on manufacturers' information. For instance, the duration of the study should be long enough to establish the facts on battery life as well as maintenance requirements and actual life span of different advanced metering technologies

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APPENDIX A: EVALUATION FRAMEWORK MATRIX

EVALUATION FRAMEWORK FOR ADVANCED WATER METERING

1. SYSTEM

No	Parameter	Value	Comment
1.1	Analysis ID	Test 1	
1.2	System name	Test system	
1.3	Suburb(s)	Test suburb	
1.4	City	Test City	
1.5	Date	Today	

2. GLOBAL PARAMETERS

No	Parameter	Value	Comment
2.1	Number of properties	1,000	
2.2	Water cost price (R/kl)	6	
2.3	Applicable water tariff (R/kl)	12.72	
2.4	Billed unmetered tariff (R/month)	200	

3. CURRENT SITUATION

Current water consumption

No	Parameter	No of properties	Unit consumption (kL/property/month)	Total consumption (kL/month)	Comment
3.1	Billed metered consumption	500	20	10000	
3.2	Billed unmetered consumption	300	30	9000	
3.3	Illegal or unbilled connections	200	40	8000	
3.4	Total/average	1000	27.00	27000	

Current payment rate

No	Fraction of properties paying for water	Fraction	No of paying properties	Income from water sales (R/month)	Comment
3.5	Billed metered consumption	50%	250	63600	
3.6	Billed unmetered consumption	40%	120	24000	
3.8	Total/average	37.0%	370	87600	

Other current parameters

No	Other parameters	Value	Comment
3.9	Fraction of demand that is on-site leakage	40%	
3.10	Ave time between meter readings (months)	2	
3.11	Meter reading cost (/meter)	R2.50	
3.12	Billing cost (/bill)	R10.00	
3.13	Meter operation & maintenance cost (/meter/month)	R3.00	
Fraction of meters failing due to:			
3.15	Meter failure (/year)	5.0%	
3.16	Vandalism and other (/year)	3.0%	
3.17	Total (/year)	8.0%	
3.18	Average household income (/month)	R3,000.00	
3.19	Unemployment rate	50%	
3.20	Volatility of community (No of protest or mass action incidences per year)	3.0	

4. PROPOSED SCHEME

Proposed system parameters

No	Parameter	Conventional metering (baseline)	Advanced metering	Comment
4.1	Meter make	framework	Prepaid	
4.2	Meter model	Positive displacement	Unknown	
4.4	SANS 1529-1 compliant?	TRUE	TRUE	
4.5	SANS 1529-9 compliant?		TRUE	
4.8	Mean battery life (years)		6	
4.9	Battery replacable in field?		TRUE	
4.10	Meter service life (years)	15	10	
4.11	Effective service life (years)	15	10	
Fraction of meters expected to fail due to:				
4.12	Water meter failure (/year)	5.0%	10.0%	
4.13	Electronics and other components (e.g. valve) failure (/year)		10.0%	
4.14	Vandalism (/year)	3.0%	7.0%	
4.15	Other (/year)	0.0%	0.0%	
4.16	Total	8.0%	27.0%	

Costs

No	Parameter	Conventional metering (baseline)	Advanced metering	Comment
4.17	Meter price (R/meter)	200	1500	
4.18	Installation cost (R/meter)	200	500	
4.20	Communication infrastructure cost (R)		120000	
4.21	Payment infrastructure cost (R)	0	80000	
4.22	Battery replacement cost (R/meter)		R 350.00	
4.23	Meter reading cost (R/meter)	R3.00	R5.00	
4.24	Meter operation & maintenance cost (/meter/month)	R3.00	R 20.00	
4.25	Billing cost (R/bill)	R10.00	0	
4.27	Additional billing system operating cost (R/month)	R0.00	0	
4.28	Additional communication system operating costs (R/month)		0	

Expected new consumption		No of properties			
4.28	Billed metered consumption (kL/property/month)	1,000	20	11	
4.29	Billed unmetered consumption (kL/property/month)	0	30	30	
4.30	Illegal consumption (kL/property/month)	0	40	40	
4.31	Total/average	1000	20.00	11.00	
4.32	No of meters installed	1000			
Fraction of properties paying for water					
4.33	Billed metered consumption		50%	75%	
4.34	Billed unmetered consumption		25%	50%	
4.36	Ave time between meter readings (months)		2	6	

APPENDIX B: SAMPLE QUESTIONNAIRE

QUESTIONNAIRE

Introduction

The University of Cape Town is conducting a study funded by the Water Research Commission (WRC) on the application of advanced water metering in South Africa. Advanced metering include all water meters with added functionality, for instance pre-payment or automatic meter reading capability.

This questionnaire is completed for a single project. Please select the most appropriate project if you have been involved in several, or complete different questionnaires for different projects. Please estimate values as well as you can, but leave out answers you don't know the answer to.

You are free not to participate or stop participating at any time. You may also remain anonymous if you choose. However, if you are willing to share your name and contact information, this will allow us to contact you in future should we have further queries. Your name and contact details will remain confidential at all times.

1.1	**Name (optional)**	
1.2	Position (optional)	
1.3	Employer (optional)	
1.4	Contact number (optional)	

Your experience with advanced metering projects

Questions	
2.1	What was the name of the advanced metering project that you were involved in?
2.2	Where was it situated?
	Province:____________________ City/Town/Rural Area:______________________
2.3	What type of advanced metering project was it?
	○ Prepaid ○ AMR ○ Data Management Add another Other:____
2.4	Who was the advanced metering project done for?

	○ NGO ○ SA Municipality ○ SA bulk water supplier ○ Non-SA institution Other:____
2.5	What was your role in the project?
	○ Technical Designer ○ Meter Supplier Representative ○ Community Liaison ○ Construction ○ Operations & Maintenance ○ Observer ○ Project management Other:____
2.6	Who were you employed by?
	○ NGO ○ SA Municipality ○ SA bulk water supplier ○ Non-SA institution ○ Consultant Contractor Other:____
2.7	Year of Implementation

System Parameters

<u>Questions</u>	
3.1	What type of consumer were provided with the metering system?
	○ Domestic – High Income ○ Domestic – Low Income ○ Industrial ○ Commercial Other:____
3.2	What was the development type?
	○ Formal Urban ○ Formal Rural ○ Informal Settlements ○ Private Development

	Other:____

Project Parameters

Questions	
4.1	How many formal and/or informal properties were provided with advanced water meters?
	Formal:________________ Informal:________________
4.2	What is the production cost of water for the municipality (in R per kl)?
4.3	What is the average water price charged to consumers (in R per kl)? (if a block tariff is used, select a tariff that would represent the average price)
4.4	If some consumers are charged a fixed monthly service fee, what is the water supply part of this fee (in R per kl)?
4.5	What is the average household income (in R per month)?
4.6	What is the unemployment rate?
4.7	What is the fraction of adults with a Grade 12 or higher qualification?
4.8	What was the reason for implementing the advanced metering project
	◯ Cost Recovery ◯ Debt Recovery ◯ Leakage Detection ◯ Demand Management Other:____
4.9	What is the free basic water allowance (kL/month)?

4.10	What fraction of the supply area get free basic water (%)?

Provide the following information for the system <u>BEFORE</u> and <u>AFTER</u> the advanced metering project was implemented:

<u>Questions</u>			**<u>Before</u>**	**<u>After</u>**
5.1	What is the fraction of properties where consumers were and are:			
		Billed based on metered consumption (%):		
		Billed a fixed rate for water (%):		
		Not billed for water at all (%):		
		Illegal connections (%):		
		Total (should be 100%)		
5.2	Average monthly consumption estimate for properties where consumers were and are:			
		Billed based on metered consumption (kL):		
		Billed a fixed rate for water (kL):		
		Not billed for water at all (kL):		
		Illegal connections (kL):		
5.3	Fraction of properties paying for water that were and are:			
		Billed based on metered consumption (%):		
		Billed a fixed rate for water (%):		
5.4	Fraction of demand that is/was on-site leakage: %			
5.5	Frequency of meter readings [monthly; bi-monthly; every 3 months; other: ________]			
5.6	Average no of incidences of community protest or mass action per year:			

5.7	Fraction of meters failing annually due to:			
		Water meter failure (%):		
		Electronics and other component (e.g. valve) failure (%):		
		Vandalism (%):		
5.8	Estimated costs for the following components:			
		Meter purchase (R/meter)		
		Installation (R/meter)		
		Battery replacement (including battery and installation) (R/replacement):		
		Total cost for required communication infrastructure		
		Total cost for required payment infrastructure		
		Meter reading (R/meter)		
		Operation and maintenance (R/month)		
		Debt-recovery for water services for the study area: (R/year)		
		Other costs (R/meter): ______________________________		
5.9	How many of the following staff would this system have ideally had to operate and maintain it adequately (use fractions for part of a person's time if applicable):			
		Plumbers:		
		Specialist meter technicians:		

Please provide information of the following parameters ONLY for the system AFTER advanced water meter implementation:

Questions

6.1	Advanced meter make and model used:
6.2	Battery life claimed by manufacturers:
6.3	Average battery life experienced:
6.4	Minimum and maximum battery lives experienced:

Other experts we could interview:

7.1	**Any other expert you could recommend to take this survey?**

Thank you – your participation is appreciated!

APPENDIX C: SURVEY RESULTS

SURVERY RESULTS

- Of the total respondents, 11 of them were low income projects
- Of the 11 respondents, 7 of them were prepaid meters, 2 of them were prepaid and AMR ; 1 of them for data management purposes and 1 of them were WMDs.
- Of the 11 respondents; 1 was working for an NGO; 4 for a consultant; 4 for a SA municipality; 1 for a bulk water supply; 1 for a contractor
- Of the 11 respondents only 4 respondents knew the production cost of water; with 3 of them claiming R10/kl and 1 claiming R6/kl
- Of the 11 low income respondents, only 5 respondents knew the average water cost; with 3 of them claiming R25/kl, 1 of them claiming R11/kl and 1 of them claiming R7.5/kl
- None of the respondents knew the amount of fixed monthly fee
- Of the 11 respondents only 6 knew the average house hold income; with 1 of them claiming R10 000/ month, 3 of them claiming R3000/month, 1 of them claiming R2000/month and 1 of them claiming R1500/month
- Of the 11 respondents, only 6 knew the unemployment rate; 1 of them claiming 70%, 1 of them claiming 50%, 3 of them claiming 40% and 1 of them claiming 30%.
- Of the 11 respondents only 5 of knew the percentage of adults with Grade 12 or higher; with 1 of them claiming 62%, 3 of them claiming 50%, and 1 of them claiming 32%.
- Of the 11 respondents; 11 of them knew the reason for implementation of advanced metering technology; 4 of them claimed it was cost recovery, 2 of them claimed cost recovery and leak detection; 1 0f them claimed Demand Management; and 1 of them claimed leak detection and demand management and 1 of them claiming cost recovery and debt recovery.
- Of the 11 respondents; 10 of them knew that they were providing FBW; with 2 of them claiming 12kl/month and 8 of them claiming 6kl/month
- Of the 11 respondents; 7 of them knew the fraction of supply aggregating FBW; with 5 of them claiming 100%, 1 0f them claiming 40 and 1 of them claiming 20%.

- Of the 11 respondents, only 7 knew the fraction of Billed based on metered consumption (%) before and after installation of advanced metering technology; with 1 claiming, 100 and 100 respectively; 1 claiming 25 and 25 respectively; 3 claiming 10 and 70 respectively, 1 claiming 10 and 70; and 1 claiming 0 and 0.

- Of the 11 respondents Billed a fixed rate for water (%); 3 (1) of them knew the fraction of consumers billed a fixed rate for water 20 to 0 respectively and 1 with 0 and 0 respectively ; with 1 not knowing fraction before implementation and 0 after implementation; with 5 not knowing both fraction.
- Of the 11 respondents, 7 (5) knew the fraction of consumers Not billed for water at all (%) with 1 claiming 100 and 100 respectively; with 3 (1) 40 and 10 respectively, 1 claiming 25 and 0 respectively; with 1 claiming 30 and 50 respectively ; with 4 not knowing the fraction.
- Of the 11 respondents; only 6 (4) knew the fraction of Illegal connections (%) before and after implementation; with 3(1) claiming 30 and 20 respectively; with 1 claiming 70 and 50 respectively; 1 claiming 50 and 75 respectively ; 1 claiming 0 and 0 respectively and 5 not knowing the fraction of illegal connections.

- Of the 11 respondents; only 3 knew the Average monthly consumption for properties where: Billed based on metered consumption (KL); with 1 claiming 5kl and 3kl respectively; with 15.66kl and 10.8kl; with 1 claiming 15kl and 15kl respectively; with 8 not knowing the consumption.
- Of the 11 respondents; only 1 knew the Average monthly consumption for properties where: Billed a fixed rate for water (KL); claiming 30kl and 30kl respectively.
- Of the 11 respondents; only 1 knew the Average monthly consumption for properties where: Not billed for water at all (KL); claiming 30kl and 30kl respectively.
- Of the 11 respondents; only 1 knew the Average monthly consumption for properties where: Illegal connections (KL) before and after implementation; claiming 30 and 30 respectively and 1 not knowing consumption before implementation while it was 8 % after implementation; and 9 (7) not knowing.

- Of the 11 respondents; only 2 knew Fraction of properties paying for water Billed based on metered consumption (%); with 1 claiming 0 and 100 respectively; 1 claiming 50 and 50 respectively; with 1 not knowing the fraction before implementation and claiming 100% after implementation and 8 (6) not knowing the fraction at all.

- Of the 11 respondents; only 1 knew Fraction of properties paying for water Billed a fixed rate for water (%); claiming 100 and 0 respectively; 1 not knowing the fraction before implementation but 0 after implementation and 9 (7) not knowing the fractions at all.

- Of the 11 respondents; only 4 (2) Fraction of demand that is onsite leakage (%); with 3(1) claiming 70 and 40 respectively; 1 claiming 5 and 5 respectively; with 1 not knowing the fraction before implementation but claiming 8% after implementation; with 7 not knowing the fraction at all.
- Of the 11 respondents; only 4 (2) knew the Frequency of meter readings; with 3(1) claiming monthly and monthly respectively; with one claiming monthly before implementation and 0 after implementation; and 7 not knowing at all.
- Of the 11 respondents; only 7 (5) Average no. of incidences of community protest; 3(1) claiming 5 and 5 respectively; 1 claiming 0 and 0 respectively; 1 claiming 1 and 0 respectively; 1 claiming 1 and 3 respectively; with 1 claiming 2 to 3 and 3 to4 respectivey and 4 not knowing at all.

- Of the 11 respondents; only 7(5) knew the Fraction of meters failing annually due to: Water meter failure (%); with 3 (1) claiming 50 and 10 respectively; 1 claiming 20 and 60 respectively, 1 claiming 5 and 40 respectively; 1 claiming greater than 1 both before and after implementation; with 1 not knowing the fraction before implementation but 2 after implementation; and 4 not knowing the fractions at all.
- Of the 11 respondents; only 6 (4) knew the Fraction of meters failing annually due to: Electronics and other components (%); with 3(1) claiming 50 and 10 respectively; with 1 claiming 10 and 7o respectively; with 1 not not knowing the fraction before (due to absence of electronics) and 1to2 after implementation; 1 not knowing the fraction

before implementation and 30 after implementation; and 5 not knowing any of the fractions at all.

- Of the 11 respondents; only 5 (3)knew the Fraction of meters failing annually due to: Vandalism; 3 (1) claiming 30 and 30 respectively; 1 claiming 40 and 15 respectively; 1 claiming not knowing the fraction before implementation and greater than 50 after implementation; and 6 not knowing any of the fractions at all.

- Of the 11 respondents; only 2; Estimated cost for the following components: Meter purchase (R/meter) ; 1 claiming 300 and 2200 respectively; 1 claiming 400 and 2500 respectively; 1 claiming 2000 before and not knowing cost after implementation; and 8 (6) not knowing any of the prices.
- Of the 11 respondents; only 2 Estimated cost for the following components: Installation (R/meter); 1 claiming 400 and 400 respectively; 1 claiming 150 and 170 respectively; and 9 (7) not knowing any of the costs
- Estimated cost for the following components: Battery replacements (including installation) (R/replacements); 1 claiming not to know price before implementation (probably because it was a conventional meter) and 350 after implementation; 1 claiming not to know the price before implementation (probably because it was a conventional meter) and 200 after implementation; and 9 (7) not knowing any of the prices.
- Of the 11 respondents; none knew Estimated cost for the following components: Total cost for required communication infrastructure (probably due to the fact that it was not applicable).
- Of the 11 respondents; none knew the Estimated cost for the following components: Total cost for required payment infrastructure (probably because it was not applicable)
- Of the 11 respondents; only 2 knew Estimated cost for the following components: Meter Reading (R/meter); 1 claiming 100 and 60 respectively; 1 claiming 4 before implementation and nothing after implementation; and 9 (7) not knowing any of the cost.
- Of the 11 respondents; only 3 knew the Estimated cost for the following components: Operation and maintanance (R/month); with 1 claiming 70 and 195 respectively; 1

claiming 100 and 4; 1 claiming 0 and 10 respectively; and 8 (6) not knowing any of the prices.

- Of the 11 respondents; only 1 knew Estimated cost for the following components: Debt-recovery for water services for study area (R/year) claiming 90 before implementation and not knowing the price after implementation; and 10 not knowing any of the prices.
- Of the 11 respondents; only 1 knew Estimated cost for the following components: Other costs (R/meter); claiming 520 after implementation and not knowing the price before implementation; and the 10 (8) not knowing any of the prices.

- Of the 11 respondents; only 3 knew the number of Staff requirements: Plumbers : 1 claiming not to know the number before implementation but 5 after implementation; 1 claiming 4 after implementation and not to know the number before implementation; 1 claiming 2 and 0 respectively; and 9 (7) not knowing the numbers at all.
- Of all the 11 respondents; only 2 knew the Staff requirements: Specialist meter technicians; with 1 claiming 0 and 3 respectively; 1 claiming not to know the number before implementation (probably because it was not needed) and 1 respectively; and 9 (7) not knowing the numbers at all.

- Of all the 11 respondents; only 4 knew the AWM make and model used; with 1 claiming Tqnovo, 1 claiming Lesira-Tech, 1 claiming WDM ; 1 claiming elster-kent; and 7 (5) know knowing the make and model.
- Of all the 11 respondents; only 3 knew the Battery life claimed by manufacturers; with 2 claiming 5 years; 1 claiming 7 to 10 ; and 8(6) not knowing the battery life claimed by manufacturers.
- Of all the 11 respondents, only 2 Average battery life experienced; both 2 claiming 3 years; and 9(7) not knowing the average battery life experienced.
- Of all the 11 respondents, only 1 knew the Minimum and maximum battery lives experienced; claiming a minimum battery life of 2 years and not knowing the maximum yet; and 10(8) not knowing the minimum and average battery life.

APPENDIX D: SENSITIVITY ANALYSIS RESULTS

Input Parameters

1. SYSTEM			
No	**Parameter**	**Value**	**Comment**
1.1	Analysis ID	Test 1	
1.2	System name	Test system	
1.3	Suburb(s)	Test suburb	
1.4	City	Test City	
1.5	Date	Today	

2. GLOBAL PARAMETERS			
No	**Parameter**	**Value**	**Comment**
2.1	Number of properties	1 000	
2.2	Water cost price (R/kl)	6	
2.3	Applicable water tariff (R/kl)	12.72	
2.4	Billed unmetered tariff (R/month)	200	

3. CURRENT SITUATION

Current water consumption

No	Parameter	No of properties	Unit consumption (kL/property/month)	Total consumption (kL/month)	Comment
3.1	Billed metered consumption	500	20	10000	
3.2	Billed unmetered consumption	300	30	9000	
3.3	Illegal or unbilled connections	200	40	8000	
3.4	Total/average	1000	27.00	27000	

Current payment rate

No	Fraction of properties paying for water	Fraction	No of paying properties	come from water sales (R/mont	Comment
3.5	Billed metered consumption	50%	250	63600	
3.6	Billed unmetered consumption	40%	120	24000	
3.8	Total/average	37.0%	370	87600	

Other current parameters

No	Other parameters	Value	Comment
3.9	Fraction of demand that is on-site leakage	40%	
3.10	Ave time between meter readings (months)	2	
3.11	Meter reading cost (/meter)	R2.50	
3.12	Billing cost (/bill)	R10.00	
3.13	Meter operation & maintenance cost (/meter/month)	R3.00	
Fraction of meters failing due to:			
3.15	Meter failure (/year)	5.0%	
3.16	Vandalism and other (/year)	3.0%	
3.17	Total (/year)	8.0%	
3.18	Average household income (/month)	R3 000.00	
3.19	Unemployment rate	50%	
3.20	Volatility of community (No of protest or mass action incidences per year)	3.0	

4. PROPOSED SCHEME

Proposed system parameters

No	Parameter		Conventional metering (baseline)	Advanced metering	Comment
4.1	Meter make		framework	Prepaid	
4.2	Meter model		Positive displacement	Unknown	
4.4	SANS 1529-1 compliant?		TRUE	TRUE	
4.5	SANS 1529-9 compliant?			TRUE	
4.8	Mean battery life (years)			6	
4.9	Battery replacable in field?			TRUE	
4.10	Meter service life (years)		15	10	
4.11	Effective service life (years)		15	10	
Fraction of meters expected to fail due to:					
4.12	Water meter failure	(/year)	5.0%	10.0%	
4.13	Electronics and other components (e.g. valve) failure	(/year)		10.0%	
4.14	Vandalism	(/year)	3.0%	7.0%	
4.15	Other	(/year)	0.0%	0.0%	
4.16	Total		8.0%	27.0%	

Costs					
No	Parameter		Conventional metering (baseline)	Advanced metering	Comment
4.17	Meter price (R/meter)		200	1500	
4.18	Installation cost (R/meter)		200	500	
4.20	Communication infrastructure cost (R)			120000	
4.21	Payment infrastructure cost (R)		0	80000	
4.22	Battery replacement cost (R/meter)			R 350.00	
4.23	Meter reading cost (R/meter)		R3.00	R5.00	
4.24	Meter operation & maintenance cost (/meter/month)		R3.00	R 20.00	
4.25	Billing cost (R/bill)		R10.00	0	
4.27	Additional billing system operating cost (R/month)		R0.00	0	
4.28	Additional communication system operating costs (R/month)			0	

Expected new consumption		No of properties			
4.28	Billed metered consumption (kL/property/month)	1 000	20	11	
4.29	Billed unmetered consumption (kL/property/month)	0	30	30	
4.30	Illegal consumption (kL/property/month)	0	40	40	
4.31	Total/average	1000	20.00	11.00	
4.32	No of meters installed	1000			
Fraction of properties paying for water					
4.33	Billed metered consumption		50%	75%	
4.34	Billed unmetered consumption		25%	50%	
4.36	Ave time between meter readings (months)		2	6	

Results of evaluation

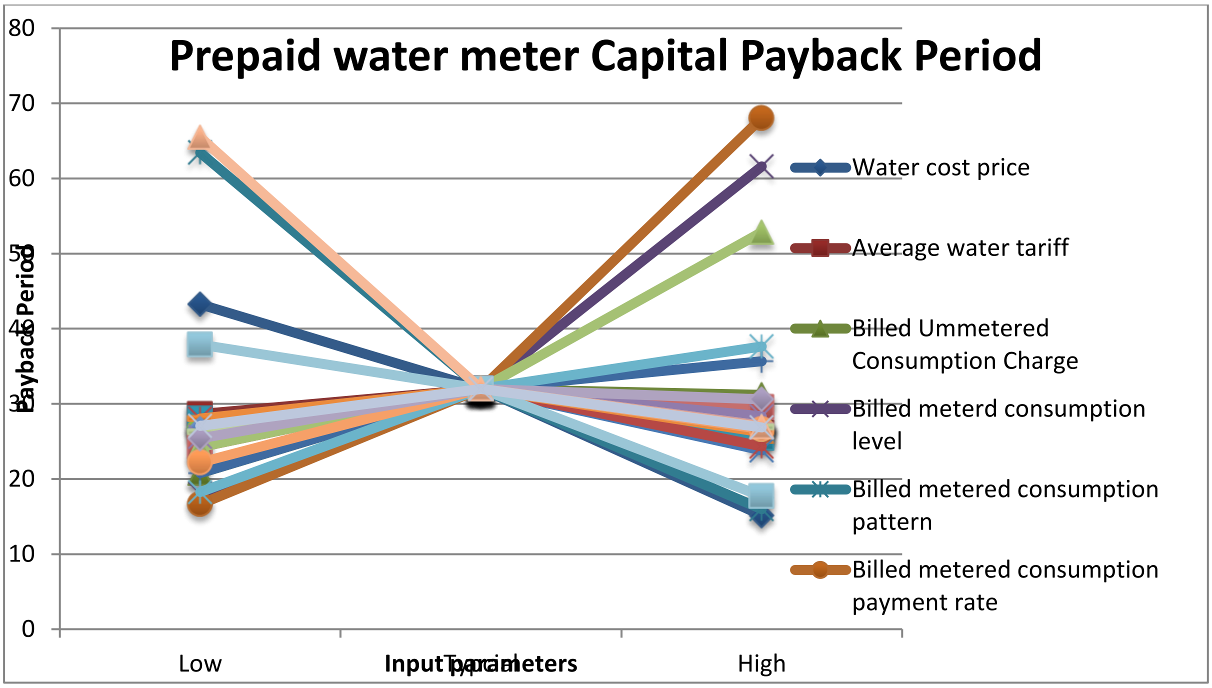
1. TECHNICAL				
No	**Property**		**Conventional metering (baseline)**	**Advanced metering**
1.1	SABS compliance		Yes	Yes
1.2	Number of meters to replace (/month)		**7**	**23**

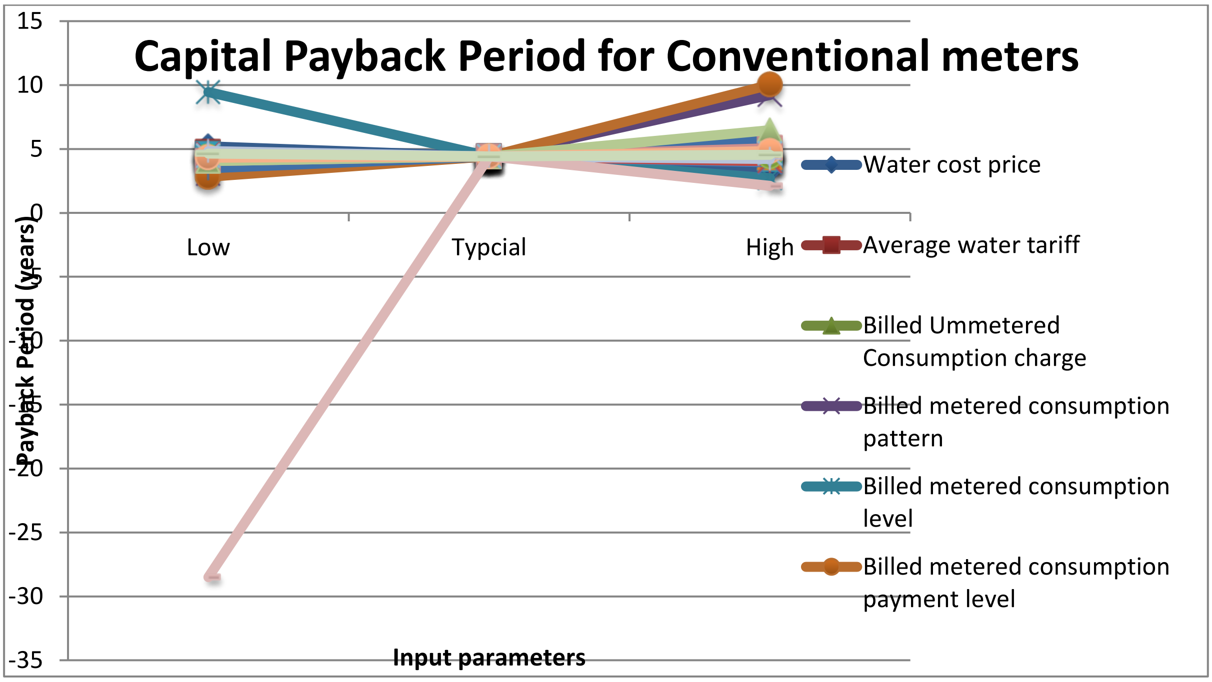
2. SOCIAL		
No	**Property**	**Value**
2.1	Current rate of meters vandalised (/year)	3.0%
2.2	Unemployment rate	50.0%
2.4	Volatility of community (No of protest or mass action incidences per year)	3
2.5	Average water bill (/month)	R394.32
2.6	Average property income (/month	R3 000.00
2.7	Water bill as a fraction of income	13.1%

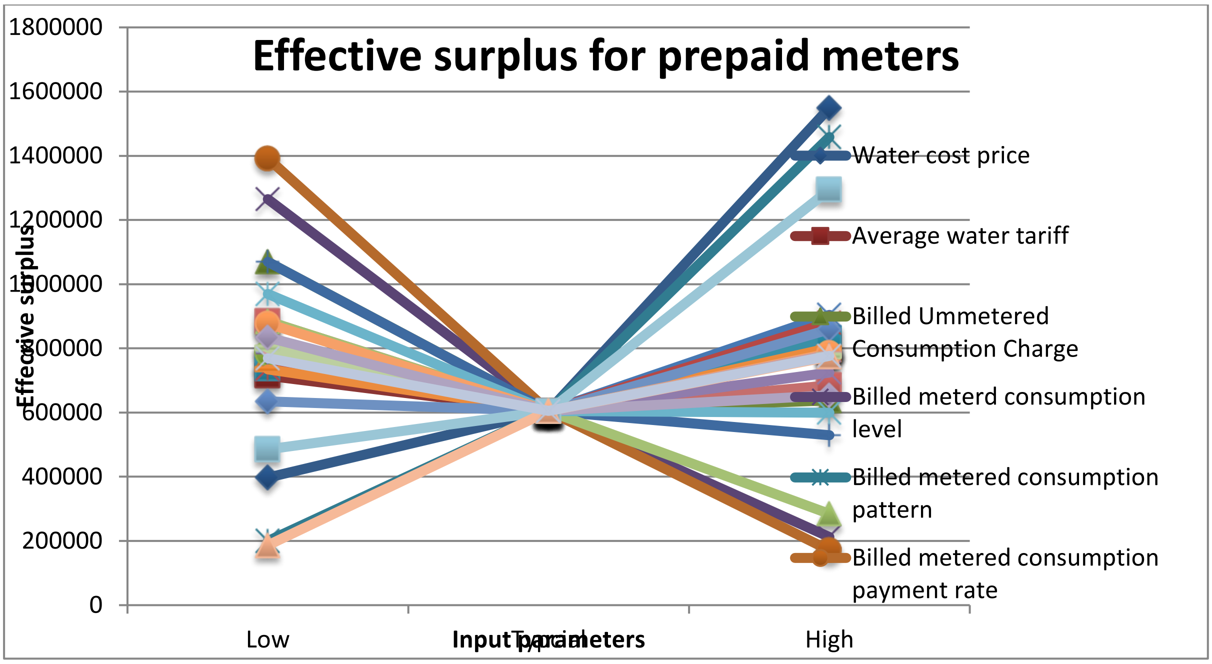
3. ENVIRONMENTAL					
No	**Consumption**	**Units**	**Current**	**Conventional metering (baseline)**	**Advanced metering**
3.1	Billed metered consumption	(kL/month)	10000	20000	11000
3.2	Billed unmetered consumption	(kL/month)	9000	0	0
3.3	Illegal consumption	(kL/month)	8000	0	0
3.4	Total consumption	(kL/month)	27000	20000	11000
3.5	Unit consumption	(kL/property/month)	27	20	11
3.6	Reduction in consumption	(kL/month)		7000	16000
3.7	Fractional reduction in consumption	-		25.9%	59.3%
3.8	No of batteries to dispose	(/year)			167

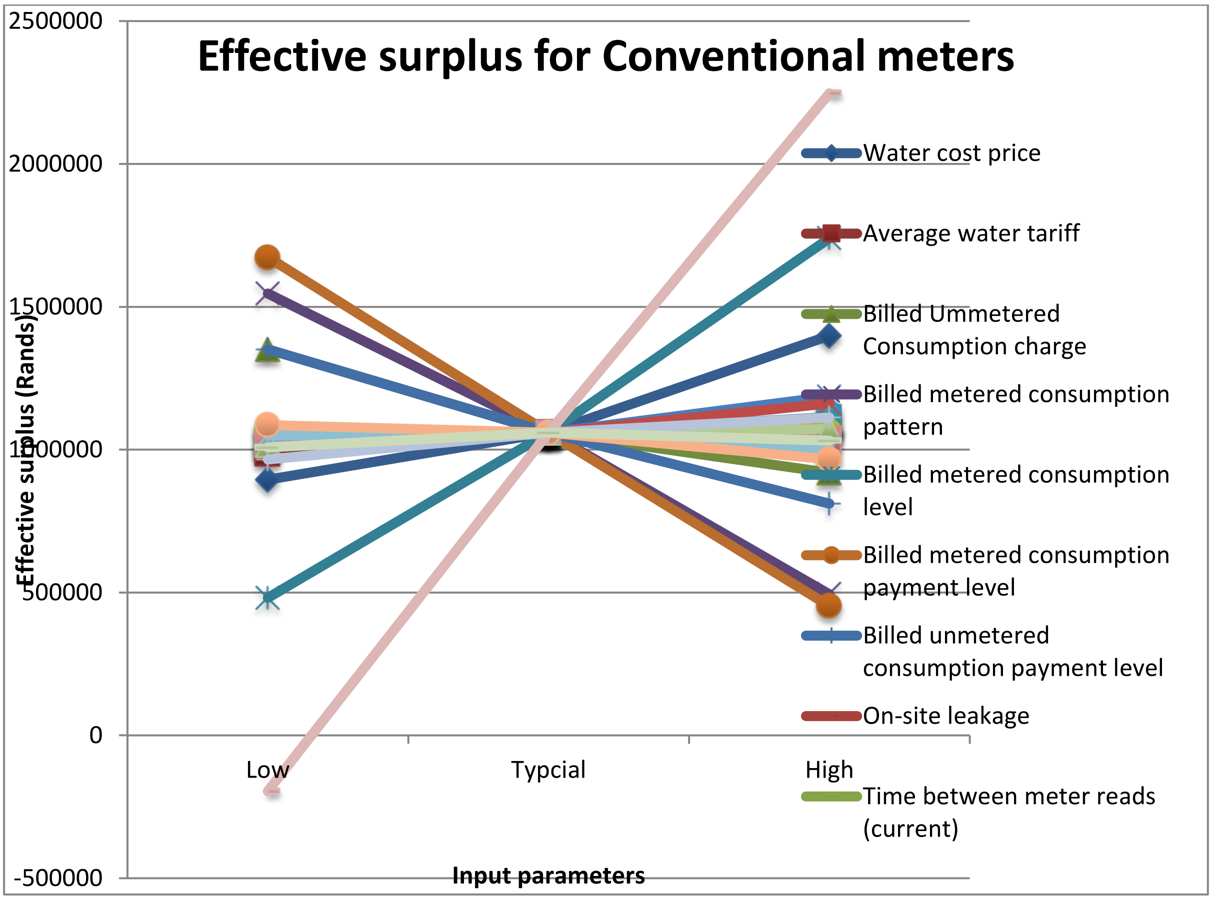
4. ECONOMIC					
No	**Income**	**Units**	**Current**	**Conventional metering (baseline)**	**Advanced metering**
4.1	Billed metered consumption	(/month)	R63 600.00	R127 200.00	R104 940.00
4.2	Billed unmetered consumption	(/month)	R24 000.00	R0.00	R0.00
4.4	Total income	(/month)	R87 600.00	R127 200.00	R104 940.00
4.5	Unit income	(/property /month)	R87.60	R127.20	R104.94
4.6	Increased income	(/month)		R39 600.00	R17 340.00
4.7	Fractional increased income			45%	20%
	Capital cost				
4.8	Water meters		R0.00	R200 000.00	R1 500 000.00
4.9	Installation		R0.00	R200 000.00	R500 000.00
4.11	Communication infrastructure cost		R0.00	R0.00	R120 000.00
4.12	Payment infrastructure cost		R0.00	R0.00	R80 000.00
4.13	Total capital cost		R0.00	R400 000.00	R2 200 000.00
4.14	Unit capital cost	(/property)	R0.00	R400.00	R2 200.00
	Operational cost				
4.15	Water production	(/month)	R162 000.00	R120 000.00	R66 000.00
4.16	Meter reading	(/month)	R625.00	R1 500.00	R833.33
	Meter operation & maintenance	(/month)	R1 500.00	R3 000.00	R20 000.00
4.17	Billing cost	(/month)	R8 000.00	R10 000.00	R0.00
4.18	Billing system operating cost	(/month)		R0.00	R0.00
4.19	Communication system operating costs	(/month)			R0.00
4.21	Failed meter replacement cost	(/month)	R16 000.00	R2 666.67	R45 000.00
4.22	Battery replacement cost	(/month)			R4 861.11
4.23	Total operating cost	(/month)	R188 125.00	R137 166.67	R136 694.44
4.24	Unit operating cost	(/property /month)	R235.16	R137.17	R136.69
4.25	Decreased operating cost	(/month)		R50 958.33	R51 430.56
	Summary				
4.26	Operational surplus	(/month)	**-R100 525.00**	**-R9 966.67**	**-R31 754.44**
4.27	Increased operational surplus	(/month)		**R90 558.33**	**R68 770.56**
4.28	Capital payment period	(months)		4.4	32.0
4.29	Expected service life	years		15	10
4.30	Effective surplus	(/year)		R1 060 033.3	R605 246.7

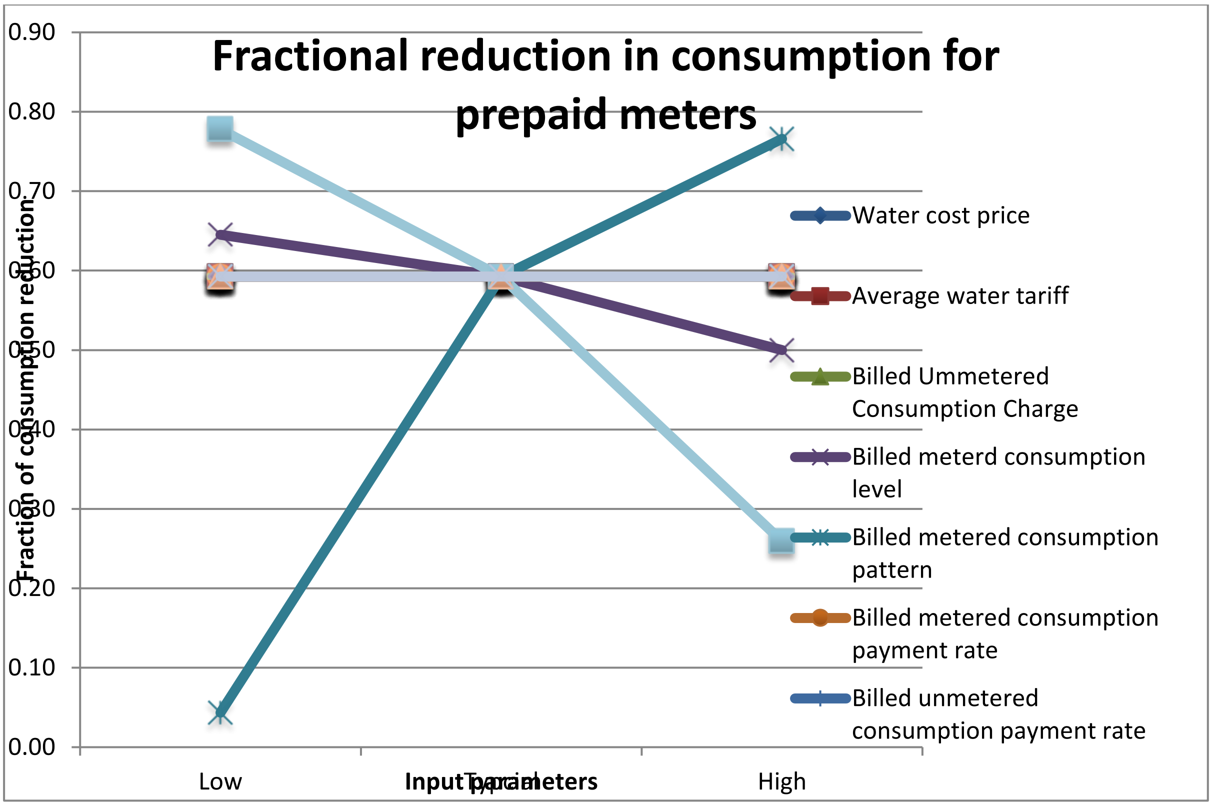
Sensitivity Charts

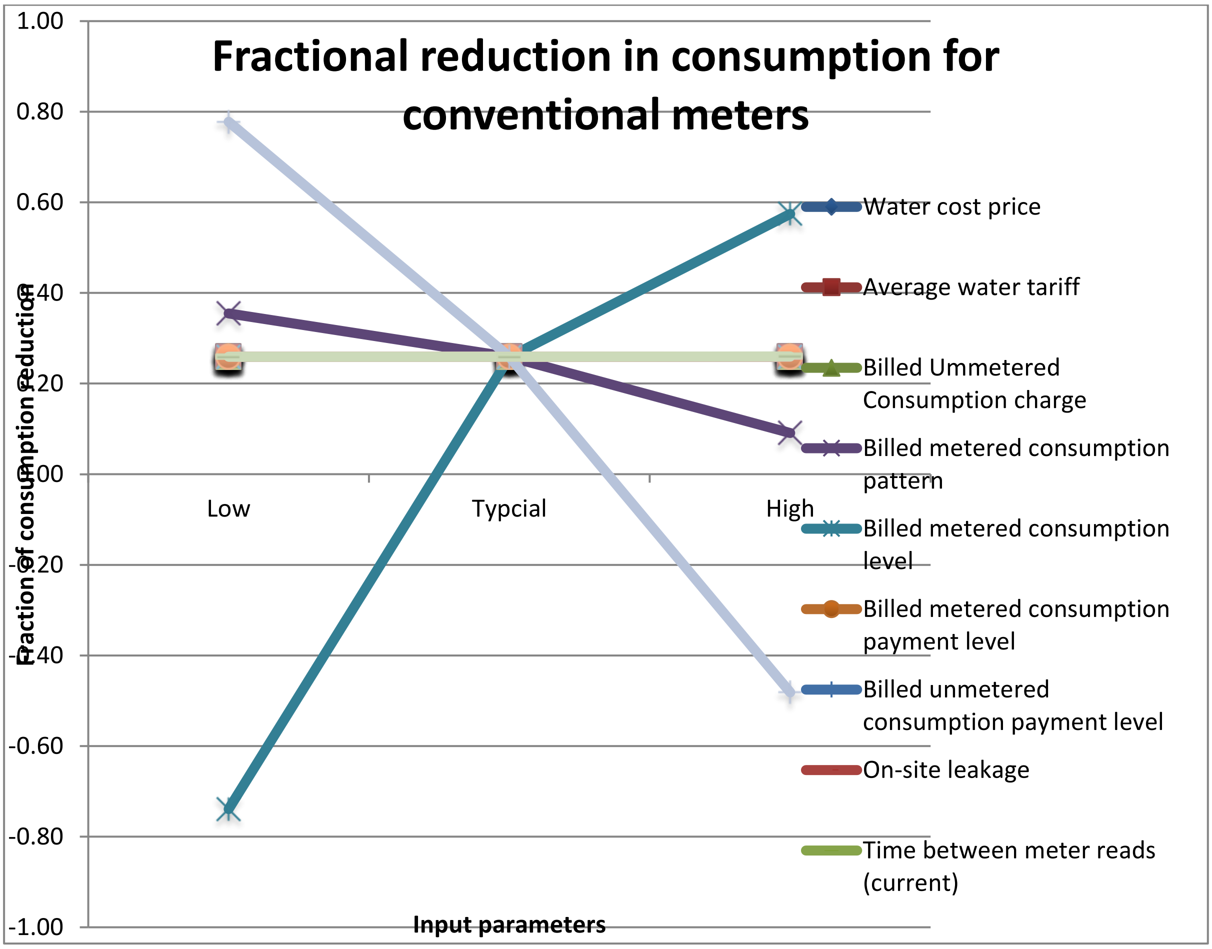


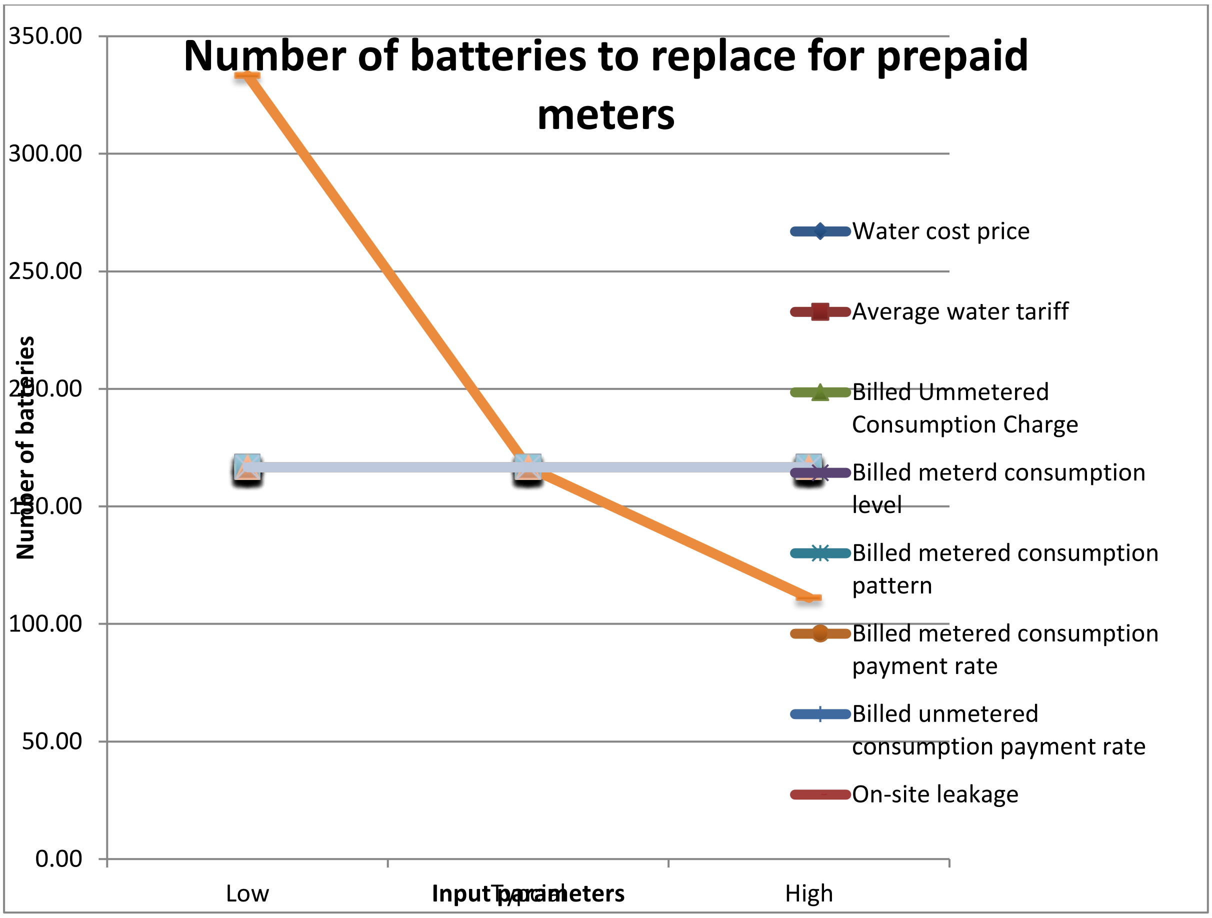



Effective surplus for prepaid meters
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
Effective surplus
Low
Typcial
High
Input parameters
Water cost price
Average water tariff
Billed Ummetered Consumption Charge
Billed meterd consumption level
Billed metered consumption pattern
Billed metered consumption payment rate


Effective surplus for Conventional meters
2500000
2000000
1500000
1000000
500000
0
-500000
Effective surplus (Rands)
Low
Typcial
High
Input parameters
Water cost price
Average water tariff
Billed Ummetered Consumption charge
Billed metered consumption pattern
Billed metered consumption level
Billed metered consumption payment level
Billed unmetered consumption payment level
On-site leakage
Time between meter reads (current)


Fractional reduction in consumption for prepaid meters
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Fraction of consumption reduction
Low
Typcial
High
Input parameters
Water cost price
Average water tariff
Billed Ummetered Consumption Charge
Billed meterd consumption level
Billed metered consumption pattern
Billed metered consumption payment rate
Billed unmetered consumption payment rate


Fractional reduction in consumption for conventional meters
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
Fraction of consumption reduction
Low
Typcial
High
Input parameters
Water cost price
Average water tariff
Billed Ummetered Consumption charge
Billed metered consumption pattern
Billed metered consumption level
Billed metered consumption payment level
Billed unmetered consumption payment level
On-site leakage
Time between meter reads (current)


Number of batteries to replace for prepaid meters
Number of batteries
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Low
Typical
High
Input parameters
Water cost price
Average water tariff
Billed Ummetered Consumption Charge
Billed meterd consumption level
Billed metered consumption pattern
Billed metered consumption payment rate
Billed unmetered consumption payment rate
On-site leakage

APPENDIX E: ETHICS CLEARANCE FORM

EBE Faculty: Assessment of Ethics in Research Projects

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zakiya Chikte (Zakiya.chikte@uct.ac.za); New EBE Building, Ph 021 650 5739). Students must include a copy of the completed form with the dissertation/thesis when it is submitted for examination.

Name of Principal Researcher/Student: Masoabi Malunga **Department: Civil Engineering**

If a Student: **Degree: MSc Eng (CIVIL)** **Supervisor: Prof. J.E van Zyl**

If a Research Contract indicate source of funding/sponsorship: Water Research Commission

Research Project Title: Advanced Water Metering and Its Application in Low Income Communities

Overview of ethics issues in your research project:

Question 1: Is there a possibility that your research could cause harm to a third party (i.e. a person not involved in your project)?	YES	NO X
Question 2: Is your research making use of human subjects as sources of data? If your answer is YES, please complete Addendum 2.	YES	NO X
Question 3: Does your research involve the participation of or provision of services to communities? If your answer is YES, please complete Addendum 3.	YES	NO X
Question 4: If your research is sponsored, is there any potential for conflicts of interest? If your answer is YES, please complete Addendum 4.	YES	NO X

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate.

I hereby undertake to carry out my research in such a way that

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

Signed by: MASOABI MALUNGA M. Malunga

	Full name and signature	Date
Principal Researcher/Student:	MASOABI MALUNGA Signed	30/08/2016

This application is approved by:

Supervisor (if applicable):	Signed	30/8/16
HOD (or delegated nominee): Final authority for all assessments with NO to all questions and for all undergraduate research.		
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.	G. Sithole Signed	31/08/2016